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Alternative Processes for Treatment of Sinter Plant Wastewater

Metcalf and Eddy, Inc., Boston, MA

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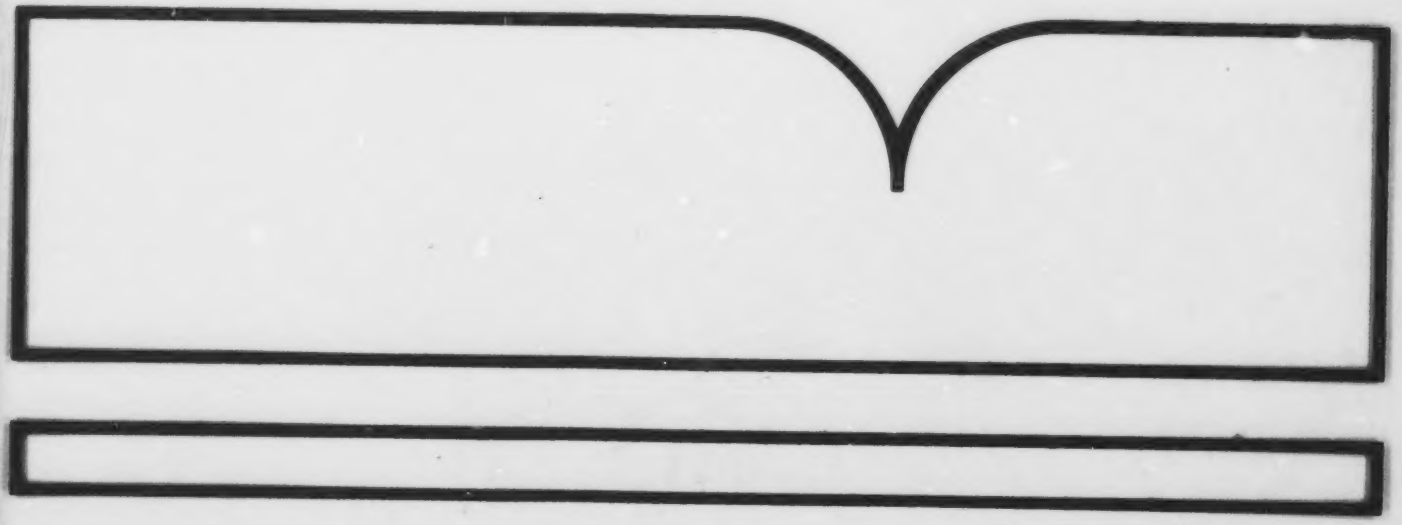

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ALTERNATIVE PROCESSES FOR TREATMENT OF SINTER PLANT WASTEWATER

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16. ABSTRACT The report gives results of an evaluation of the effectiveness of two treatment alternatives in achieving best available technology (BAT) standards: (1) direct filtration, using a dual media filter; and (2) hydroxide precipitation with lime, followed by dual media filtration. With the promulgation of Best Available Technology Economically Achievable Effluent Guidelines and Standards for Iron and Steel Manufacturing, a greater degree of treatment than the clarification process normally used to achieve best practicable technology (BPT) standards may be required for sintering plant blowdown. Evaluation of a third alternative, alkaline chlorination, was attempted; but, due to nonrepresentative test conditions, the effort was abandoned. Based on the limited data generated during the study, it appears that either treatment alternative tested would produce an effluent that would meet the promulgated BAT standards. Direct filtration is less expensive and requires less maintenance and operator attention than the hydroxide precipitation/filtration alternative. The treatment processes were tested, using two EPA-owned mobile pilot plant trailers: one contained a clarifier, used to simulate preclarification; and the other contained the hydroxide precipitation clarifier, chemical tanks, dual media filter, and associated equipment.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS		b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group	
Pollution	Hydroxides	Pollution Control	13B	07B
Sintering	Calcium Oxides	Stationary Sources	13H	
Waste Water	Chlorination			07C
Water Treatment	Clarification			07A
Iron and Steel Industry	Precipitation		11F	07D
Sintering Furnaces	Filtration		13I, 13A	

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ABSTRACT

With the promulgation of Best Available Technology Economically Achievable (BAT) Effluent Guidelines and Standards for Iron and Steel Manufacturing, a greater degree of treatment than the clarification process normally used to achieve BPT standards may be required for Sintering Plant blowdown. The purpose of this study was to evaluate the effectiveness of two treatment alternatives in achieving the BAT standards. These treatment alternatives are: (1) direct filtration, using a dual media filter and (2) hydroxide precipitation with lime followed by dual media filtration. Evaluation of a third alternative, alkaline chlorination, was attempted, but due to nonrepresentative test conditions this effort was abandoned.

Testing of the treatment processes was performed using two EPA-owned mobile pilot plant trailers. One trailer contained a clarifier which was used to simulate a preclarification step and the other trailer contained the hydroxide precipitation clarifier, chemical tanks, dual media filter and associated equipment.

Based on the limited data generated during this study, it appears that either of the treatment alternatives tested would produce an effluent that would meet the promulgated BAT standards. Direct filtration is less expensive and requires less maintenance and operator attention than the hydroxide precipitation-filtration alternative.

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ABBREVIATIONS AND SYMBOLS

ABBREVIATIONS

ACFM	-- actual cube feet per minute
BAT	-- Best Available Technology (Economically Achievable)
BCT	-- Best Conventional Pollutant Control Technology
BPT	-- Best Practicable Control Technology Currently Achievable
BOF	-- Basic Oxygen Furnace
MWWTS	-- Mobile Wastewater Treatment System
NPDES	-- National Pollution Discharge Elimination
ORP	-- Oxidation-reduction potential
$SCFH/FT^2$	-- Standard cubic feet per hour per square foot
SS	-- suspended solids
TS	-- total solids
TRC	-- total residual chlorine

SYMBOLS

CaF_2	-- calcium fluoride
$Ca(OH)_2$	-- hydrated lime
Cr(III)	-- trivalent chromium
Cr(VI)	-- hexavalent chromium
$Cr(OH)_3$	-- chromic hydroxide

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(*) Formerly, Industrial Environmental Research Laboratory

SECTION 1

INTRODUCTION

Under the Effluent Guidelines and Standards for the Iron and Steel Manufacturing Point Source Category promulgated May 27, 1982, Best Available Technology (BAT) effluent limitations for the Sintering Subcategory are based on the application of a higher degree of treatment than BPT Clarification alone. Pilot plant studies were conducted to evaluate two treatment alterntives for removal of selected pollutants for which BAT limitations had been proposed (Note 1).

The treatment alternatives piloted were direct filtration employing a dual media pressure filter, and hydroxide precipitation with lime followed by dual media filtration. A third alternative, Alkaline chlorination, was attempted but, due to an intermittent production schedule during this test phase, representative samples were not collected. The wastewater tested was blowdown from the venturi scrubber and cyclonic mist eliminator wet air pollution control system. Wastewater analyses quantified suspended solids, fluoride, cyanide, phenols, oil and grease, and various heavy metals and priority pollutants.

The major objective of the testing program was to develop a data base from which the alternative systems could be evaluated both individually and comparatively. The data base was generated through laboratory analyses of regularly collected samples and monitored operating conditions during

Note 1. This study was conducted prior to the promulgation on May 27, 1982 of the BAT Effluent Limitations for the Iron & Steel Manufacturing Point Source category. The basis for the selection of pollutant parameters for evaluation of the alternative treatment systems investigated in this study was the proposed guidelines made public in December 1980. This report has been updated after the study to indicate the promulgated guidelines.

the pilot plant operation. To assess the performance of each process, the data was analyzed with respect to the removal of selected pollutants. Capital and operating costs were developed to assess the economics of each treatment alternative. An overall comparative evaluation was then made based on both performance and economics.

SECTION 2

CONCLUSIONS

STUDY CONCLUSIONS

The results of the pilot studies for the treatment of sinter plant blowdown have indicated that both direct filtration and hydroxide precipitation followed by filtration are effective in removing the selected BAT pollutants to the levels required by the effluent guidelines and limitations.

Direct filtration significantly reduced suspended solids, oil and grease and heavy metals levels. A slight reduction in phenols levels was observed. None of the pollutant parameters for which effluent limitations have been promulgated exceeded these limitations.

Hydroxide precipitation followed by filtration also produced an effluent that met all of the limitations. Influent cyanide concentrations and, consequently, effluent concentrations met both the maximum and average BAT limitations throughout the study. As expected, the data showed that neither process removed cyanide.

Since the pH of the influent wastewater was fairly high and good removal of metals, suspended solids and fluoride was observed in the preclarifier, the benefits of raising the pH further by lime addition were marginal. Optimization of the clarification step in BPT by a lower overflow rate and polymer addition, may be able to achieve an effluent quality comparable with that achieved by direct filtration.

Both treatment trains appear to be capable of providing the degree of treatment required to meet effluent limitations. Direct filtration, however, is considerably less expensive and requires less operator attention and maintenance than hydroxide precipitation followed by filtration.

STUDY CONSTRAINTS AND LIMITATIONS

The primary objective of the testing program was to develop data for alternative treatment systems as applied to

sinter plant wastewater. Although the treatment processes that were evaluated in this study have been previously tested or applied for the treatment of metal plating wastewaters and other iron and steel wastewaters, no data existed for their application to the treatment of sinter plant wastewater. The EPA requested the development of 12 data points for each treatment alternative, to be accomplished by 8-hour composite sampling during 24-hour per day pilot plant operation. This approach was taken primarily because of time constraints. It is important that the results of the testing program be viewed in the proper perspective, with due consideration of the limitations attendant to both the duration and the method of testing.

Direct Filtration and Hydroxide Precipitation

The data for the two treatment alternatives evaluated were generated under controlled operating conditions over four days of operation. The test results, therefore, reflect a very limited range of influent conditions and pilot plant operating parameters. Long-term changes in the raw wastewater composition, temperature and pH, and variations in treatment plant operation, may produce results that are different from those observed during the test period.

Bench tests were conducted with the objective of pre-establishing certain operating conditions, primarily chemical dosage and pH. However, most pilot plant operating parameters were selected on the basis of experience to give a practicable and/or reasonably conservative system, within the constraints of the existing pilot equipment. No process optimization was attempted during the pilot plant operation.

Comparison of effluent quality achieved by each treatment alternative with the BAT limitations was based on average and maximum values for twelve 8-hour composite samples of effluent, and not 30-day average and maximum values of 24-hour composites as would be required for permit compliance.

In summary, the pilot plant test results are indicative of the range of effluent concentrations achievable by the processes tested with the raw wastewater characteristics that existed at Armco Steel's sinter plant during the pilot testing period. The average and maximum effluent concentrations do not necessarily represent the levels that can be routinely achieved industry-wide by a full-sized system.

Alkaline Chlorination

BAT Treatment Alternative No. 3, alkaline chlorination followed by filtration, was attempted on the Armco Steel sinter plant blowdown. The effort was terminated due to numerous problems and malfunctions relating to the sinter plant operation.

A field crew was on-site to run the alkaline chlorination testing in April 1981. During this time Armco experienced numerous, sudden plant shutdowns. These unexpected shutdowns caused numerous operating problems at the pilot plant. In addition, due to an ore handlers strike, Armco changed from the high lime sinter burden that is normally used and which had been used throughout the study to a high iron burden not normally used by the plant. As a result, no representative data was collected for the alkaline chlorination treatment train. The scheduled move of the pilot trailer to the next site prohibited further testing at the Armco sinter plant to generate the desired data.

SECTION 3

RECOMMENDATIONS

Based on limited data from this study, optimized BPT clarification to minimize overflow rates plus polymer addition followed by filtration is identified as being most advantageous for the treatment of sinter plant blowdown. This incorporates advantages of both processes - the relatively low cost of direct filtration and the flocculation and additional settling provided by the hydroxide precipitation process. It was apparent from the data that the additional metals removal provided by the hydroxide precipitation was due to a reduction in the net residual suspended solids concentration rather than the increase in pH since the concentrations of soluble metals were virtually unchanged. Additional testing of this treatment scheme would provide a more conclusive data base.

The constraints of short-term piloting should be recognized. The pilot plant data base was limited to the wastewater quality encountered at the time of the testing and the process operating conditions employed. It was not possible to develop data for a broad range of wastewater quality or to optimize process operation in the short period of pilot testing. Therefore, it is recommended that the existing pilot plant data base be augmented by longer term pilot studies designed to optimize treatment processes and evaluate a reasonable range of variables, or even full-scale testing, if possible.

It is also recommended that the data base be confirmed on a sinter plant with an acid burden and acid blowdown. Many sinter plants have a blowdown with a pH that may be as low as 2.0. In this type of system the makeup of dissolved metals would be completely different.

SECTION 4

TESTING PROGRAM DESCRIPTION

The testing program was conducted to provide data on the treatment of blowdown from a wet air pollution control recycle system for a sinter plant. The plant site where the testing was conducted was a sinter plant that utilizes a venturi scrubber and cyclone mist eliminator for air pollution control. Two process trains were evaluated:

1. Direct Filtration

2. Hydroxide Precipitation followed by Filtration.

Direct filtration and hydroxide precipitation followed by a polishing filter are two of the alternative treatment models that EPA considered in the development of the BAT effluent limitations (5). The process flow trains for these treatment alternatives are presented in Figure 1.

Trailer-mounted pilot facilities were employed for testing. The pilot plant consisted of two existing EPA owned units, part of the Mobile Wastewater Treatment System (MWWTS) designed to provide treatment for a nominal throughput of 5 gallons per minute (gpm).

The selected BAT pollutant parameters for the sintering subcategory include suspended solids, pH, fluoride, cyanide, phenols, oil and grease, and certain heavy metals and priority pollutants. These parameters were employed in developing a data base for evaluation of the alternative treatment processes. They are presented in Table 1.

WASTEWATER TREATMENT PROCESSES

Filtration

Filtration is common to all the proposed alternative BAT treatment models considered by EPA (5). In BAT-1, direct filtration of sintering blowdown was evaluated for removal of

1. DIRECT FILTRATION

2. HYDROXIDE PRECIPITATION WITH LIME

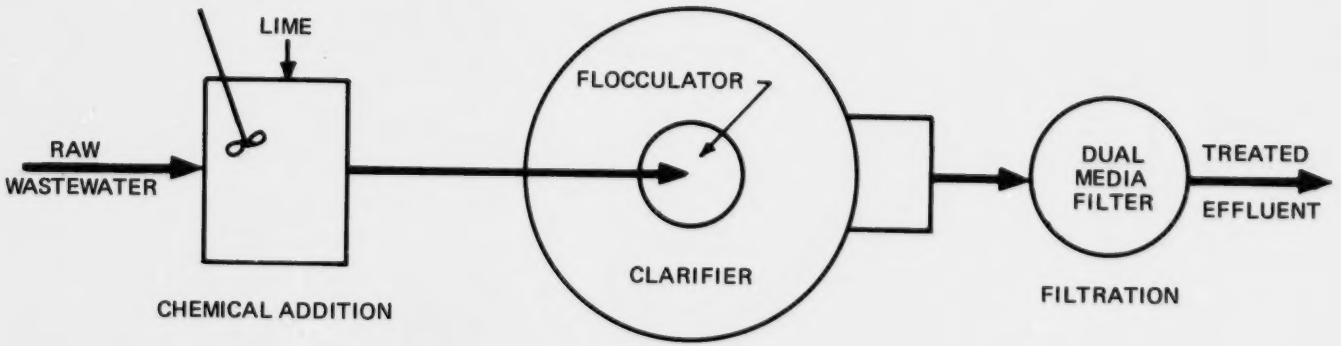

Figure 1. Pilot Plant Process Flow Trains

suspended solids and other pollutants such as metals which may be in the particulate (nonsoluble) form. In BAT-2, hydroxide precipitation, filtration of clarified effluent is included as a polishing step for the removal of metal hydroxides formed.

TABLE 1. POLLUTANT PARAMETERS SELECTED FOR PILOT TESTING OF SINTER PLANT BLOWDOWN

Phenols (4 AAP)	Cadmium
Fluoride	Chromium
Suspended Solids	Copper
pH	Lead
Fluoranthene	Nickel
Phenol	Silver
Chrysene	Zinc
Pyrene	

Hydroxide Precipitation with Lime

Precipitation of heavy metals as hydroxides through the addition of lime is a well-established technology. Lime is added to raise the pH to a level found to be the most suitable for optimum precipitation of the metal hydroxides which are of concern. The metal hydroxide precipitates form a floc which can then be removed from the water by gravity settling. This floc can entrain particulates, including metals, and thus enhance their removal. In addition to metals removal, hydroxide precipitation with lime can also remove fluoride by providing a source of calcium for precipitation of calcium fluoride.

Although hydroxide precipitation is a relatively simple process, it has several limitations. The effectiveness of the process in removal of heavy metals is a function of the solubility of the metal hydroxides which in turn is a function of pH and water quality. Thus removal of heavy

metals is limited to the solubility of of the metal hydoxides in the particular wastewater matrix under consideration.

Metal hydroxides are amphoteric with respect to the pH of the solution. Their solubility is a function of pH, and each metal hydroxide has a minimum solubility for some corresponding pH value. At a pH higher or lower than this value, the metal hydroxides are more soluble. The optimum pH for precipitation occurs at a different pH value for every metal. At a pH where the solubility of one metal hydroxide is minimized, the solubility of another may be relatively high. This can present problems in achieving low residual concentrations for all heavy metals that are of concern. The solubility curves for heavy metal hydroxides are presented in Figure 2 (2).

Formation and removal of metal hydroxides is also a function of the water quality. Behavior of metal hydroxides can vary with the complex nature of the wastewater matrix and the presence of complexing agents. Actual solubility of metal hydroxides may be greater than the theoretically predicted solubilities in water.

PLANT SITE

General

Pilot testing for hydroxide precipitation and direct filtration of sinter plant blowdown was conducted at the Armco Steel Corporation, Middletown, Ohio Works. The Armco sinter plant has been on-line since late 1974. The plant, which converts iron-bearing waste fines into blast furnace feed materials, has an average production rate of 150 tons per hour. During the pilot plant test period, the feed to the sinter plant consisted of approximately 70 percent BOF slag, 15 percent taconite fines, 12 percent blast furnace scrubber sludge and 3 percent coke fines.

Recirculation System

Waste gases are cleaned by a venturi scrubber and cyclonic mist eliminator (Figure 3). Water is recirculated from the mist eliminator tank and supplied to the scrubber throat and inlet at a rate of 1,800 gpm. Make-up water is supplied to the mist eliminator tank at a rate of 400 gpm (150 gpm of treated water and 250 gpm of contaminated treated water from the other sinter plant sources). Blowdown is taken directly from the bottom of the mist eliminator tank at a rate of 325 gpm. This comprises about 15 percent of the mist eliminator flow.

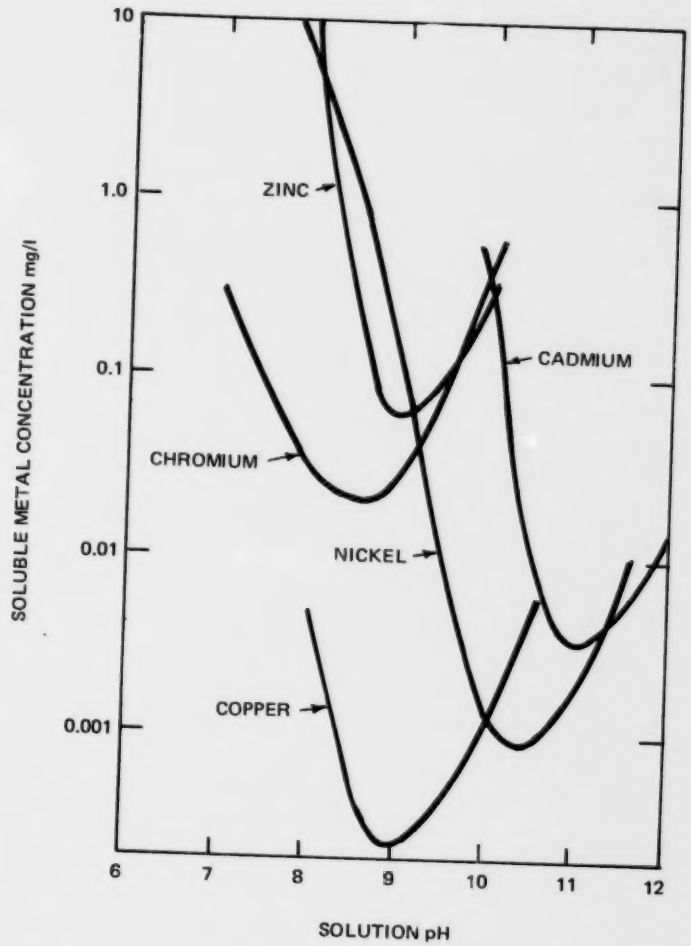

Figure 2. Solubilities of Metal Hydroxides as a Function of pH (2)

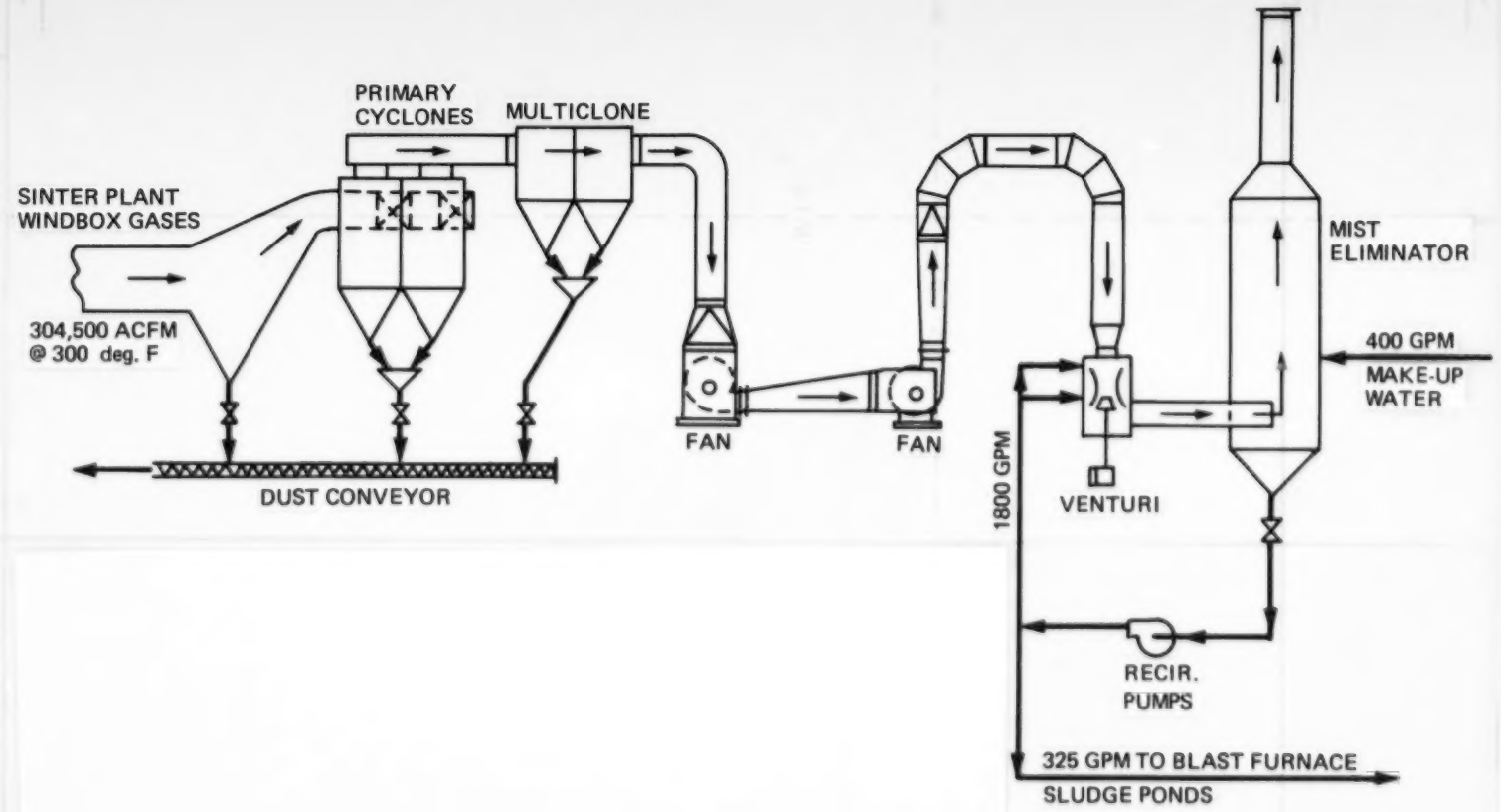

Figure 3. Armco Steel Corporation – Scrubber System Flow Diagram

Wastewater Treatment System

The blowdown (325 gpm) is treated in settling lagoons along with blowdown from the blast furnace and underflow from the water softening plant. Effluent from these lagoons is pumped to three cone-shaped clarifiers where it undergoes further clarification enhanced by addition of a polyelectrolyte prior to discharge to the Great Miami River. A schematic of the existing wet air pollution control system is presented in Figure 4.

Pilot Plant Location and Schedule

The two MWWTS trailers were set up next to the settling ponds. Because the sinter plant blowdown is mixed in the ponds with the blast furnace blowdown and water softening underflow, the influent to the pilot plant was tapped from the sintering blowdown line prior to its discharge into the pond.

The pilot plant was set up and operated from January 27, 1981 to February 24, 1981. This time period included set-up, system restoration and modification, actual pilot plant operation and sampling, and shut-down. The Armco sinter plant was shut-down for the month of March and the first week of April for maintenance and repairs. On April 7, 1981 the field crew arrived at the plant to begin pilot plant modifications to start running two-stage alkaline chlorination. The alkaline chlorination test phase, however, was not completed due to the many problems encountered at the sinter plant.

PILOT SYSTEM DESCRIPTION

Mobile Wastewater Treatment System Trailers No. 1 and No. 2 were employed in the testing program for treating sintering blowdown by the alternative BAT treatment models. Trailer No. 1 contained the chemical treatment system and filtration equipment. Trailer No. 2 contained a clarifier for the preclarification step. Diagrams of Trailers No. 1 and No. 2 are presented in Figures 5 and 6, respectively.

Preclarification

The clarifier in Trailer No. 2 served as a preclarifier to simulate BPT treatment prior to the BAT process trains. Influent flow was introduced to the clarifier through a self-priming centrifugal feed pump. The clarifier is 4.25 feet in diameter and 3.3 feet deep. At a flow rate of 15 gallons per minute (gpm), the overflow rate was 1,530 gallons

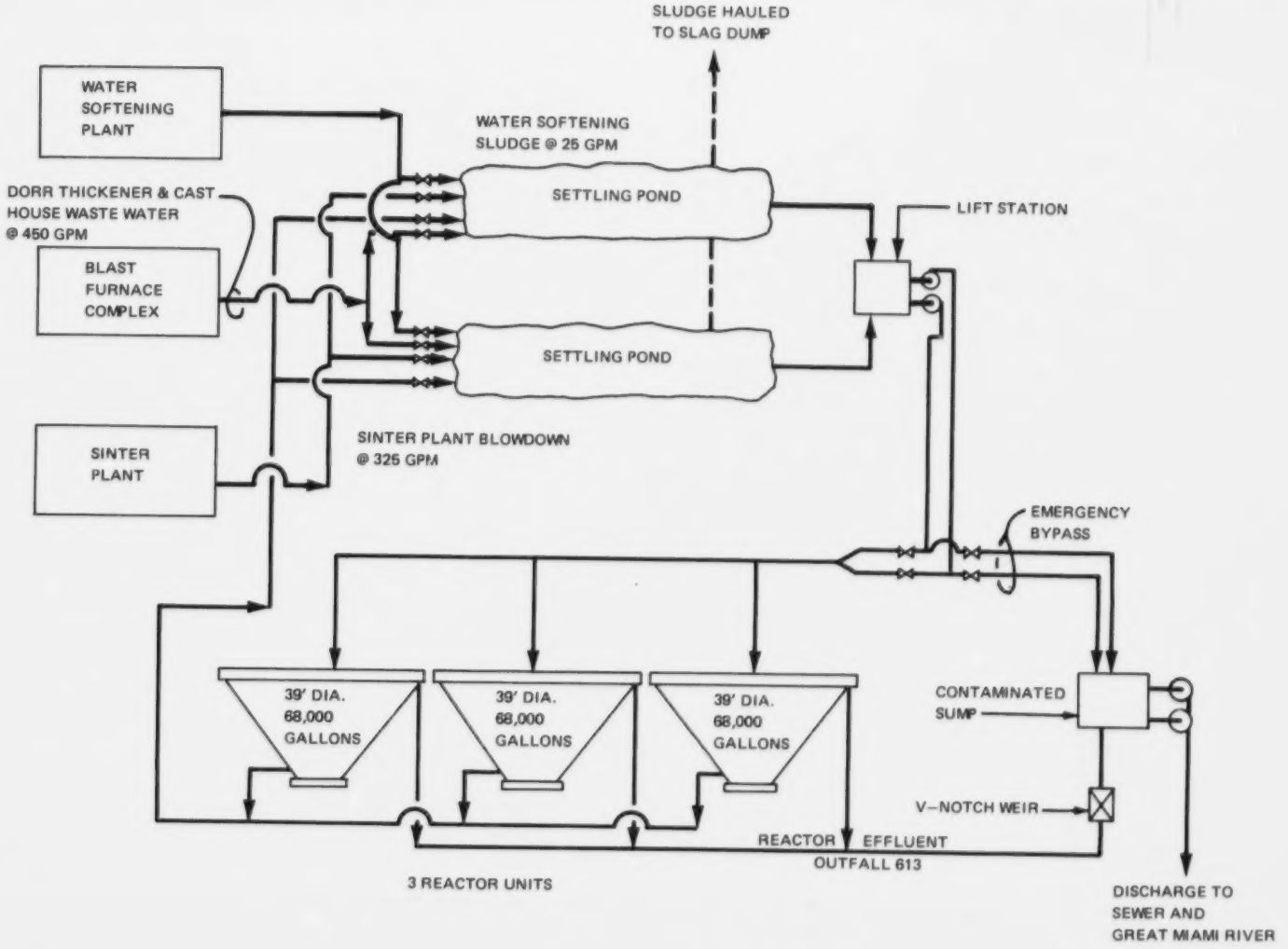

Figure 4. Armco Steel Corporation Wet Air Pollution Control System

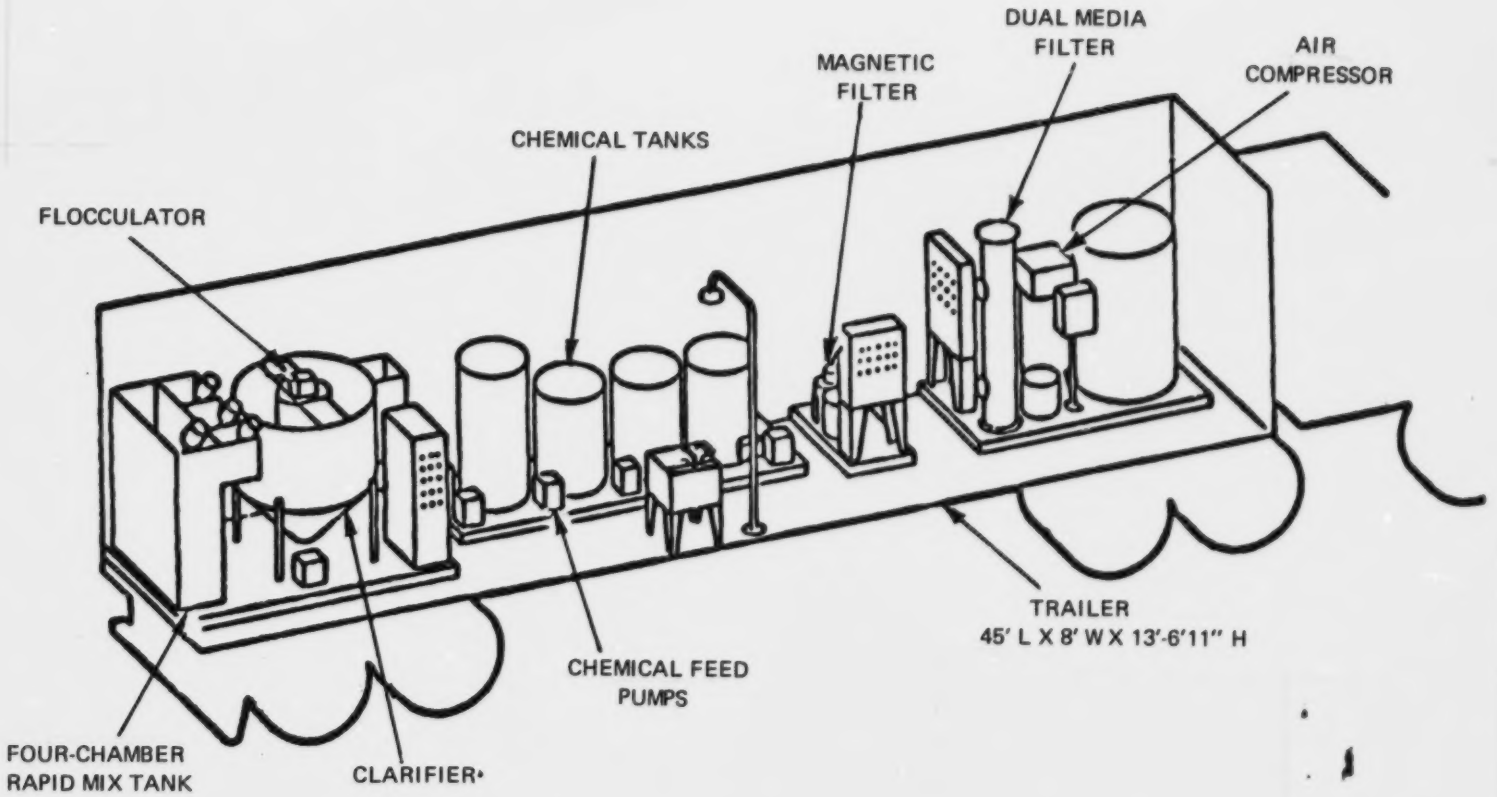

Figure 5. Steel Plant Mobile Treatment System - Trailer No. 1

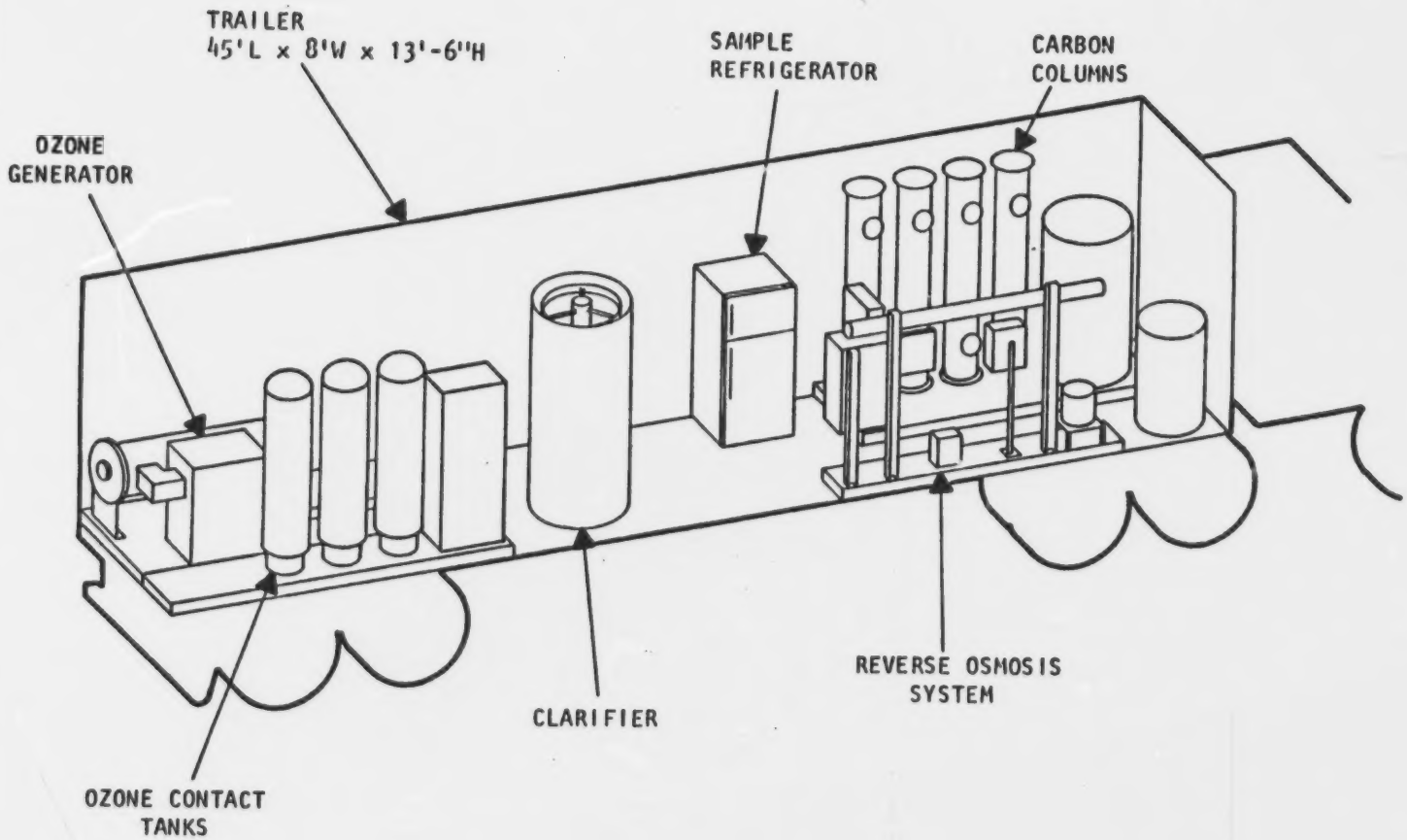

Figure 6. Steel Plant Mobile Treatment System - Trailer No. 2

per day per square foot (gpd/ft^2) or 1.06 gpm/ft^2, and the detention time was 24 minutes.

Flocculator-Clarifier and Chemical Feed System

The influent to the MWWTS Trailer No. 1 was introduced through a self-priming centrifugal feed pump, which fed the wastewater to the rapid mix chambers. The influent flow was indicated, recorded and totalized. There are four rapid mix chambers (capacities: 1 chamber at 360 gallons, 2 chambers at 60 gallons, and 1 chamber at 12 gallons) with various flow mode and bypass capabilities. The flocculator has a variable speed turbine (0 to 180 ft/sec/ft) with a flocculation time of 8.3 minutes at 6 gpm. The clarifier is 6 feet in diameter and 3.5 feet deep, with an overflow rate of 350 gpd/ft^2 or 0.25 gpm/ft^2 and a 2-hour detention time at 6 gpm. The sludge pump can remove sludge at 0 to 25 gpm from the bottom of the clarifier for recycle to the rapid mix chambers or for wasting.

Effluent from the clarifier flows over V-notch weirs and into the effluent launders which direct it to a 60-gallon collection tank. This tank can serve as a rapid mix chamber when necessary. Clarifier effluent is available for further downstream treatment in any other part of the system. Scum and other floatable material may be removed by a manually operated skimmer which directs the scum into a collection trough and to the sludge wasting line.

There are four chemical stock tanks (capacities: 1 tank at 165 gallons and 3 tanks at 100 gallons; the large tank and one of the small tanks are equipped with rapid mixers). Associated with these tanks are six chemical feed pumps, each with the capability of providing 0 to 8 gallons per hour (gph). In addition to these pumps there is a high rate lime feed pump suitable for lime slurry recirculation. Chemicals may be introduced either to the rapid mix tanks or in-line to the influent stream.

Filtration

The trailer contains a pressure filter with a 1.0-square foot filter area and a maximum media depth of about 3 feet. Flow is controlled automatically by a flow control valve downstream from the filter which opens more as head loss increases to maintain a set flow rate. A self-priming centrifugal feed pump (rated for 10 gpm at 55 psi) draws filter feed from the clarifier effluent collection tank or reactor. Flow through the filter is indicated, recorded, and totalized.

Filtrate normally flows into a 500-gallon backwash tank, providing a source of backwash water and a reservoir for continuous flow to downstream processes if needed. The backwash cycle can be initiated either automatically (by a head loss sensing system or a timer) or manually.

SECTION 5

TESTING PROCEDURES

The major objective of the pilot plant testing was to develop a data base to evaluate alternative technology for treating sinter plant blowdown. Prior to the pilot plant testing, bench scale tests were conducted in an attempt to establish chemical requirements and select parameters for process operation. Because the actual pilot testing was short-term, only one set of operating conditions was tested for each process during the pilot plant operation. Process control variables were maintained constant. This provided no means of optimizing process control through use of the pilot plant. Any optimization, therefore, had to be determined to the degree possible in the bench scale tests. This placed a limitation on the data base that was developed.

BENCH SCALE TESTS

A bench scale test was conducted for hydroxide precipitation at the Metcalf & Eddy Laboratory in Boston on an 8-hour composite sample of Armco's raw sinter plant blowdown. The sample was collected at a point prior to discharge into the settling ponds where mixing with blast furnace blowdown and water softening underflow would occur; therefore, no settling had taken place prior to its collection. To simulate BPT settling, the sample was thoroughly mixed, allowed to settle for 30 minutes and the supernatant siphoned off to be used for the bench tests. The purpose of the tests was to characterize the wastewater for the selected pollutant parameters for the sintering subcategory and to determine the operating pH and lime dosage for the hydroxide precipitation testing.

In the jar test, a range of operating pH levels was tested, including a control which received no pH adjustment. The composite sample was divided into six 1-liter aliquots. Lime was added to each of the sample aliquots to raise the pH of each aliquot by a different degree. Key pollutant and operating parameters including metals, suspended solids, pH and lime dosage, were monitored to evaluate the operating conditions. The test results showed no clear optimum pH. A

of 10 was, therefore, selected for the pilot plant operation based on previous experience with wastewaters containing similar metals.

A jar test was also performed for alkaline chlorination. Sample aliquots were adjusted to pH 10.5, then a different sodium hypochlorite dosage was added to each. Residual chlorine concentrations, oxidation-reduction potential (ORP) and the key pollutant parameters, ammonia and cyanide, were monitored. All bench test data are presented in Appendix B.

GENERAL PILOT PLANT OPERATION

Pilot plant process flow trains are presented in Figure 1 for the direct filtration and hydroxide precipitation flow schemes. Operating and testing procedures for the two treatment trains are presented in this section.

Filtration

Dual media filtration was employed both for direct filtration and as a polishing filtration step for hydroxide precipitation. Many variables affect filtration. Among these are media specifications, wastewater characteristics, hydraulic loading rates, modes of operation, head loss, and backwash. Process control variables are turbidity, suspended solids, hydraulic loading rates, and backwash rate and duration.

The following test conditions were selected for operation of the dual media filter:

1. Media. The media selected were anthracite and sand, which were compatible with the wastewater being treated. The size range is specified as follows:

Media	Size	Specific gravity	Depth, in.
Sand	0.4-0.8 mm	2.6	12
Anthracite	1.0-1.5 mm	1.5	24

2. Hydraulic Loading Rate. The raw wastewater and the clarified effluent from the hydroxide precipitation were filtered at 5 gpm/ft^2.

3. Mode of Operation. Each test was conducted at a constant rate and variable head.

4. Head Loss. The filter was operated at a preset inlet pressure. The pressure differential was monitored using the pressure taps on the filter column.

5. Backwash. The filter was backwashed following each test run regardless of the necessity for backwash. This insured that operating conditions were consistent for each run. The backwash cycle consisted of a low rate backwash flow (2 gpm/ft^2) concurrent with an air scour of 60-80 standard cubic feet per hour per square foot ($SCFH/ft^2$) for 2 minutes followed by a high rate backwash flow (15 gpm/ft^2) for 10 to 15 minutes.

Filtration performance is generally monitored by headloss across the filter bed and by determination of suspended solids or turbidity of influent and effluent samples. During the testing period both differential pressure across the filter and turbidity were monitored at the end of each run.

Hydroxide Precipitation

Based on bench scale data and previous experience with heavy metals precipitition, it was decided that the tests would be run at an operating pH of 10. A slurry of hydrated lime ($Ca(OH)_2$) was applied to maintain pH 10 in the rapid mix tank. Lime addition was controlled by a pH controller with its input probe located in the rapid mix tank. Both influent and rapid mix tank pH were indicated and recorded at the instrumentation panel. Daily maintenance of the pH electrodes included cleaning and recalibration using a standard buffer solution.

For the hydroxide precipitation testing, a lime slurry of between 5 and 6 percent $Ca(OH)_2$ was prepared. The slurry was recirculated continuously in the lime feed loop from the stock tank and back. The pH controller regulated lime slurry addition by opening and closing a solenoid valve on the lime feed line, which was a short branch off of the recirculation loop. Necessary back pressure in the recirculation line to permit control of lime feed through the solenoid valve was created through the use of a diaphragm valve.

Following chemical addition in the rapid mix tanks, the treated wastewater flowed by gravity to the flocculator-clarifier for flocculation and settling. Clarifier overflow was collected and pumped to the dual media filter.

The sludge produced was collected in the clarification cone. Once the sludge storage capacity of the clarifier was

attained, sludge was wasted at the rate of production. Sludge production rates were determined by the operator by taking a sample of the flocculated wastewater, allowing it to settle for 30 minutes and measuring sludge produced on a volume basis. The sludge pump was operated intermittently by a timer to draw off sludge from the clarifier cone.

SAMPLING AND ANALYTICAL PROCEDURES

Sample Collection

Each process train was operated to obtain at least 12 sampling periods (test runs). Composite periods of 8 hours were selected so that testing of each process train could be performed in 4 to 5 days. Composite samples of the raw wastewater (pilot plant influent), clarifier effluent and final (filtered) effluent were collected by automatic samplers. The sample collection and analytical schedule is presented in Table 2 for selected BAT pollutant parameters and additional parameters for process control. All BAT parameters were determined from composite samples collected over each 8-hour test run.

Composite pilot plant influent, clarifier effluent (during the hydroxide precipitation test phase) and final effluent samples were collected and analyzed for every test run and all process trains. Composite preclarifier influent samples were collected and analyzed for at least one out of every three precipitation process test runs and sometimes more frequently.
All composite sampling periods were 8 hours. The analyses from the composite samples made up the data base for process evaluation.

Grab samples were collected for oil and grease and process control and observation. At least once per test run, influent, clarifier effluent and final effluent grab samples were collected and monitored for pH, temperature and turbidity.

Grab samples of sludge (clarifier underflow) were collected for selected hydroxide precipitation test runs. At least one sample was collected per day (three test runs).

Sample Preservation and Handling

All composite samples were divided in the field for preservation at the end of each run. Following the division of the composite samples into the appropriate sample containers, sample preservatives were added as specified in Table 2. All samples were packed in ice after preservation

TABLE 2. SAMPLE COLLECTION AND ANALYTICAL SCHEDULE

Parameter	Reason for analysis: Performance evaluation	Reason for analysis: Process control	Analysis performed on-site	Sample location: Raw wastewater	Sample location: MWWTS pilot feed	Sample location: Clarifier effluent[1]	Sample location: Final effluent	Container type	Sample volume	Preservation	EPA method No.
Ammonia-N	X			CD	CS	C	CS	Plastic	1,000 ml	H_2SO to pH<2,4°C	350.2
Cyanide	X			CD	CS	C	CS	Plastic	1,000 ml	NaOH to pH >12,4°C 0.008% $Na_2S_2O_3$	335.2
Phenols	X			CD	CS	C	CS	Glass	1,000 ml	H_3PO_4 to pH <4,4°C	420.1
Fluoride	X			CD	CS	C	CS	Plastic	500 ml	Cool, 4°C	340.2
Oil & Grease	X			GD	GS	G	GS	Glass	1,000 ml	H_2SO_4 or HCl to pH <2 Cool, 4°C	413.1
Suspended Solids	X	X		CD	GS	C	CS	Plastic	1,000 ml	Cool, 4°C	160.1
pH	X	X	X	GD	GS	G	GS	Determine on site			
Cadmium	X			CD	CS	C	CS	Plastic	500 ml for all metals		213.2
Chromium	X			CD	CS	C	CS	Plastic			218.2
Copper	X			CD	CS	C	CS	Plastic			220.2
Lead	X			CD	CS	C	CS	Plastic			239.2
Nickel	X			CD	CS	C	CS	Plastic			249.2
Silver	X			CD	CS	C	CS	Plastic			272.2
Zinc	X			CD	CS	C	CS	Plastic			289.2
Chlorine residual		X	X					Determine on site			
Turbidity		X	X	G	GS	GS	GS	Determine on site			
Temperature		X	X	G	GS	GS	GS	Determine on site			
Extractable priority pollutant organics	X			C	C	C	C	Glass 1 gallon			625
Purgeable priority pollutant organics	X			G	G	G	G	Glass Vial 125 ml			624

Legend:
G - Grab Sample
C - Composite Sample
D - Day
S - Shift (8 or 12 hour test run)

1. Once per day on alkaline chlorination runs, once per shift on hydroxide precipitation runs.

and shipped in coolers to the analytical laboratories by express air freight.

Analyses

All analyses with the exception of oil and grease and priority pollutant organics were performed by the Metcalf & Eddy laboratory in Boston. Priority pollutant organics and oil and grease samples were analyzed by Stewart Laboratories, Inc. in Knoxville, Tennessee. All wastewater samples were analyzed for the parameters listed in Table 2. EPA analytical methods approved for the National Pollutant Discharge Elimination System (NPDES) were employed for all analyses. The specific methods that were employed are identified in Table 2.

The analytical work performed for this study incorporated quality control analyses as 15 percent of the total number of analyses. These quality control analyses included, method and reagent blanks, field replicates, laboratory replicates, standards and spikes. The quality control data was monitored on a daily basis. All samples received by the laboratory were logged in and processed immediately upon receipt in order to assure that holding times were not exceeded.

In addition to the total metals analyses, which were performed on every sample, samples from selected test runs were analyzed for soluble metals. Because membrane filtration equipment was not available at the testing site, the samples analyzed for soluble metals were filtered in the analytical laboratory.

Sludge samples were characterized by total solids and total metals analyses. In addition to the characterization, Buchner Funnel Tests were conducted to assess dewaterability of the sludges generated. The specific filtration resistance value determined by the test was employed as a quantitative index of dewaterability.

SECTION 6

RESULTS AND DISCUSSION

The analytical data collected during this study is presented in this section along with a discussion of the effects that each of the two treatment technologies had on the selected pollutant parameters for the sintering subcategory. Two of these parameters, cadmium and silver, were present at very low concentrations in the raw waste and were removed to a concentration below their analytical detection limits by the preclarifier. In this study, therefore, cadmium and silver were removed by BPT treatment and will not be discussed further.

DIRECT FILTRATION

The analytical data from the 12 direct filtration runs are presented in Table 3. The data have been summarized in Table 4. In order to insure representative values, unusually high or low values have been dropped from the averages and ranges presented in Table 4.

Suspended Solids Removal

The results demonstrated that direct filtration effectively reduced the level of suspended solids to a concentration of less than 10 ppm. With the exception of Run No. 12, the effluent level of suspended solids ranged from 1 ppm to 7 ppm with an average concentration of 3 ppm. This demonstrated a removal efficiency of 98 percent. With the small range of effluent values it can essentially be said that suspended solids were reduced by direct filtration to the same effluent level in each of the runs, showing no dependence on the influent levels.

Fluoride

Although it was expected that no reduction would occur in the fluoride concentration with direct filtration, some reduction was observed. The reduction in fluoride concentrations may be due to a small portion of the soluble fluoride forming insoluble calcium fluoride (CaF_2) with the natural hardness in the water and being removed by filtration in particulate form.

TABLE 3. DIRECT FILTRATION TEST RESULTS

Run No.	pH			TOTAL SUSPENDED SOLIDS (ppm)		
	Preclar Inf.	Pilot Inf.	Filter Eff.	Preclar Inf.	Pilot Inf.	Filter Eff.
1	--	7.9	7.6	--	210	1
2	8.6	8.4	8.7	190	75	7
3	--	8.3	8.3	--	15	2
4	8.3	8.3	8.4	2000	170	3
5	--	7.5	7.6	--	184	5
6	7.3	7.3	7.1	5210	141	4
7	--	6.8	6.9	--	2	3
8	--	9.1	9.0	--	71	2
9	--	7.1	7.2	--	91	3
10	7.7	7.6	7.6	700	130	2
11	--	7.8	7.9	--	130	2
12	7.8	7.8	7.9	120	140	87

Run No.	FLUORIDE (ppm)			TOTAL PHENOL (ppm)		
	Preclar. Inf	Pilot Inf.	Filter Eff.	Preclar. Inf.	Pilot Inf.	Filter Eff.
1	--	21	12	--	0.04	0.08
2	94	20	24	0.04	0.01	0.01
3	--	26	21	--	0.04	0.04
4	140	29	34	0.04	0.04	0.04
5	--	18	14	--	0.04	0.03
6	250	11	12	0.12	0.05	0.04
7	--	9	10	--	0.30	0.22
8	--	16	10	--	0.22	0.14
9	--	15	11	--	0.10	0.06
10	45	18	11	0.60	0.22	0.06
11	--	15	43	--	0.10	0.10
12	15	22	13	0.34	0.10	0.06

Run No.	CYANIDE (ppm)			OIL & GREASE (ppm)		
	Preclar. Inf.	Pilot Inf.	Filter Eff.	Preclar. Inf	Pilot Inf.	Filter Eff.
1	--	0.12	0.13	--	--	--
2	0.047	0.079	0.034	--	--	--
3	--	0.051	0.044	--	--	--
4	0.094	0.075	0.087	--	--	--
5	--	0.15	0.094	--	--	--
6	0.068	0.16	0.15	--	--	--
7	--	0.21	0.25	270	12	<5
8	--	0.25	0.26	190	<5	9
9	--	0.16	0.15	120	20	<5
10	0.070	0.12	0.09	28	<5	<5
11	--	0.15	0.11	310	<5	<5
12	0.040	0.15	0.12	30	<5	<5

TABLE 3. (CONTINUED) DIRECT FILTRATION TEST RESULTS

RUN NO.	TOTAL CADMIUM (PPM)		
	PRECLAR. INF.	PILOT INF.	FILTER EFF.
1	-	<0.010	<0.010
2	0.015	<0.010	<0.010
3	-	<0.010	<0.010
4	<0.010	<0.010	<0.010
5	-	<0.010	<0.010
6	0.034	<0.014	<0.010
7	-	0.020	0.013
8	-	<0.010	<0.010
9	-	<0.010	<0.010
10	0.014	<0.010	<0.010
11	-	<0.010	<0.010
12	0.010	<0.010	<0.010

TOTAL CHROMIUM (PPM)		
PRECLAR. INF.	PILOT INF.	FILTER EFF.
-	0.470	0.370
0.580	0.440	0.370
-	0.480	0.310
0.400	0.500	0.430
-	0.330	0.310
0.410	0.260	0.051
-	0.160	<0.010
-	0.130	0.018
-	0.110	0.018
0.110	0.050	0.030
-	0.120	0.046
0.310	0.130	0.037

RUN NO.	TOTAL COPPER (PPM)		
	PRECLAR. INF.	PILOT INF.	FILTER EFF.
1	-	0.048	0.020
2	0.160	0.028	0.020
3	-	0.037	<0.020
4	0.079	<0.020	<0.020
5	-	<0.020	<0.020
6	0.220	0.086	<0.020
7	-	0.053	<0.020
8	-	0.035	<0.020
9	-	0.026	<0.020
10	0.160	0.045	<0.020
11	-	0.032	<0.020
12	0.150	0.028	0.026

TOTAL LEAD (PPM)		
PRECLAR. INF.	PILOT INF.	FILTER EFF.
-	0.110	<0.020
0.550	0.180	<0.020
-	0.340	<0.020
0.790	0.130	<0.020
-	0.100	<0.020
0.290	0.190	<0.020
-	0.270	<0.020
-	0.110	<0.020
-	0.046	<0.020
0.400	0.034	<0.020
-	0.064	<0.020
0.440	0.110	<0.020

RUN NO.	TOTAL NICKEL (PPM)		
	PRECLAR. INF.	PILOT INF.	FILTER EFF.
1	-	0.016	<0.010
2	0.097	0.026	0.014
3	-	0.014	<0.010
4	0.032	<0.010	<0.010
5	-	0.011	<0.010
6	0.290	0.035	<0.010
7	-	0.042	0.016
8	-	0.011	<0.010
9	-	0.032	0.023
10	0.054	0.024	0.016
11	-	0.019	0.011
12	0.230	0.017	0.019

TOTAL SILVER (PPM)		
PRECLAR. INF.	PILOT INF.	FILTER EFF.
-	<0.010	<0.010
<0.010	<0.010	<0.010
-	<0.010	<0.010
<0.010	<0.010	<0.010
-	<0.010	<0.010
0.025	<0.010	<0.010
-	<0.010	<0.010
-	<0.010	<0.010
-	<0.010	<0.010
0.010	<0.010	<0.010
-	<0.010	<0.010
0.013	<0.010	<0.010

TOTAL ZINC (PPM)		
PRECLAR. INF.	PILOT INF.	FILTER EFF.
-	2.6	0.43
11	0.49	0.35
-	0.70	0.09
6.7	0.39	0.06
-	0.52	0.07
13	0.67	0.16
-	1.7	0.47
-	0.46	0.14
-	0.37	0.19
20	0.46	0.12
-	NS	0.06
17	0.27	0.06

TABLE 4. DIRECT FILTRATION DATA SUMMARY

Parameter	Preclarifier Influent (ppm) Mean	Range	Number of Samples*	Pilot Influent (ppm) Mean	Range	Number of Samples*	Filter Effluent Mean	Range	Number of Samples*	Average % Removed
Suspended Solids	1644	120-5210	5	123	15-210	11	3	1-7	11	98%
pH	7.9	7.3-8.6	5	7.8	6.9-9.1	12	7.8	6.9-9.0	12	--
Fluoride	109	15-250	5	18	9-29	12	16	10-34	11	11%
Phenol	0.23	0.04-0.60	5	0.10	0.01-0.30	12	0.07	0.01-0.22	12	30%
Cyanide	0.07	0.047-0.094	4	0.14	0.075-0.250	12	0.130	0.034-0.26	12	--
Oil & Grease	158	28-310	6	<9	<5-20	6	<6	<5-9	6	--
Total Cadmium	0.017	<0.010-0.034	5	<0.011	<0.010-0.020	12	<0.010	<0.010-0.013	12	--
Total Chromium	0.362	0.110-0.580	5	0.265	0.050-0.500	12	0.170	0.010-0.430	12	36%
Total Copper	0.150	0.079-0.220	5	0.038	0.020-0.086	12	<0.020	<0.020-0.026	12	--
Total Lead	0.490	0.290-0.790	5	0.140	0.034-0.340	12	<0.0200	<0.0200	12	>86%
Total Nickel	0.140	0.032-0.290	5	<0.021	<0.01-0.042	12	0.013	<0.01-0.023	12	38%
Total Silver	0.0130	<0.010-0.025	5	<0.010	<0.010	12	<0.010	<0.010	12	--
Total Zinc	13	6.7-20	5	0.78	0.27-2.6	11	0.18	0.06-0.47	12	77%

*Except for the Preclarifier, for which fewer samples were taken, the number of samples may vary due to unusually high or low data values which were dropped from the averages and ranges. These values do appear in the results listed in Table 3.

Phenols

A reduction in the phenols concentration was observed in nearly 50 percent of the test runs, contrary to what would be expected. The possibility of phenols being adsorbed onto the anthracite portion of the filter media was considered. It was also possible that phenols were adsorbed onto suspended solids matter or oil and grease in the wastewater. This would account for the decrease in phenols concentration observed after preclarification.

Cyanide

No cyanide reduction was observed, as would be expected.

Oil and Grease

As indicated in Table 3, oil and grease was mostly removed in the preclarification step. However, in Runs 7 and 9 for which oil and grease were present in the pilot influent, it was removed to a level below 5 ppm by direct filtration. Oil and grease removal should be accomplished by BPT treatment.

Metals Removal

Chromium --

A significant chromium reduction occurred during filtration, averaging 38 percent. The effluent concentrations ranged from <0.010 ppm to 0.430 ppm with an average of 0.17 ppm. The variability in the effluent was due to varying amounts of soluble chromium in the influent. The greatest reductions occurred when the soluble chromium concentrations were the lowest (Table 5). This was true not only for total chromium, but for particulate chromium also. When the soluble chromium concentration was high, as in Runs 1, 2 and 3 only a small percentage of the particulate chromium was removed. The removal for Runs 1, 2, and 3 was 29, 26, and 50 percent, respectively. When the soluble chromium concentration was much lower than the total chromium concentration, a much greater fraction of the particulate chromium was removed. In Runs 6, 9, 10, and 12, the soluble chromium concentrations were low. For these runs the percent of particulate chromium removed was 88, 84, 40, and 72 percent, respectively. It appears that the influent particle size is smaller as the amount of soluble chromium in the wastewater increases.

Copper and Lead

In almost all of the direct filtration test runs, both copper and lead were removed to levels below their analytical

TABLE 5. COMPARISON OF TOTAL AND SOLUBLE METALS LEVELS FOR DIRECT FILTRATION

	Run No. 1				Run No. 2				Run No. 3				Run No. 6			
	Pilot Influent (ppm)		Filter Effluent (ppm)		Pilot Influent (ppm)		Filter Effluent (ppm)		Pilot Influent (ppm)		Filter Effluent (ppm)		Pilot Influent (ppm)		Filter Effluent (ppm)	
Parameter	Total	Soluble	Total	Soluble	Total	Soluble	Total	Soluble	Total	Soluble	Total	Soluble	Total	Soluble	Total	Soluble
Cadmium	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	0.014	<0.010	<0.010	<0.010
Chromium	0.470	0.160	0.370	0.150	0.440	0.130	0.370	0.140	0.480	0.140	0.310	0.140	0.260	0.021	0.051	0.023
Copper	0.048	<0.020	0.020	<0.020	0.028	<0.020	0.020	-	0.037	<0.020	<0.020	<0.020	0.086	<0.020	<0.020	<0.020
Lead	0.110	<0.020	<0.020	<0.020	0.180	0.120	<0.020	-	0.340	<0.020	<0.020	<0.020	0.190	<0.020	<0.020	<0.020
Nickel	0.016	0.011	<0.010	0.010	0.026	<0.010	0.014	-	0.014	<0.010	<0.020	<0.010	0.035	0.016	<0.010	<0.010
Silver	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	-	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010
Zinc	2.6	0.47	0.43	0.14	0.49	-	0.35	-	0.70	-	0.09	<0.010	0.67	0.21	0.16	0.16

	Run No. 9				Run No. 10				Run No. 12			
	Pilot Influent (ppm)		Filter Effluent (ppm)		Pilot Influent (ppm)		Filter Effluent (ppm)		Pilot Influent (ppm)		Filter Effluent (ppm)	
Parameter	Total	Soluble	Total	Soluble	Total	Soluble	Total	Soluble	Total	Soluble	Total	Soluble
Cadmium	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	-	<0.010	<0.010	<0.010	0.010
Chromium	0.110	<0.010	0.018	<0.010	0.050	0.012	0.030	-	0.130	0.019	0.037	0.014
Copper	0.026	<0.020	<0.020	<0.020	0.045	<0.020	<0.020	-	0.028	<0.020	0.026	<0.020
Lead	0.046	<0.020	<0.020	<0.020	0.034	0.020	<0.020	-	0.110	<0.020	<0.020	<0.020
Nickel	0.032	0.027	0.023	0.021	0.024	<0.010	0.016	-	0.017	<0.010	0.019	<0.010
Silver	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	-	<0.010	<0.010	<0.010	<0.010
Zinc	0.37	0.08	0.19	0.08	0.46	-	0.12		0.27	<0.01	0.06	<0.010

detection limit of 0.02 ppm. Referring to Table 5 it can be seen that nearly all of the copper and lead present in the sinter plant blowdown was present in the particulate form, accounting for the high removal efficiency. Nearly total removal of these metals was achieved for the sinter plant blowdown by direct filtration.

Nickel --

Although the level of nickel in the influent was quite low, further reduction did occur in the filter, averaging 38 percent. The nickel concentration in the effluent ranged from <0.010 ppm to 0.023 ppm with a mean value of 0.017 ppm. Nickel was also primarily present in particulate form, although soluble nickel predominated in the influent in a few of the runs.

Zinc--

An overall reduction of 77 percent of the average zinc concentration was achieved by direct filtration. The effluent concentration ranged from 0.06 to 0.47 ppm with a mean value of 0.18 ppm. The variability was in part due to varying levels of soluble zinc in the influent.

HYDROXIDE PRECIPITATION

The analytical data from the 12 hydroxide precipitation runs are presented in Table 6. The data have been summarized in Table 7. Unusually high or low values have been dropped from the summarization to insure representative results.

Suspended Solids

Very little suspended solids removal took place in the clarifier. In some cases the suspended solids concentrations were higher in the clarifier effluent than in the clarifier influent due to solids carryover. Suspended solids removal in the filter after clarification was very good.

Fluoride Removal

Generally, significant fluoride removal did not occur, although removal was observed in some of the runs. The effluent concentration ranged from 11 ppm to 24 ppm with an average value of 16 ppm. The removal of fluoride was achieved by precipitation of calcium fluoride (CaF_2) with calcium being introduced into the wastewater by addition of lime. Optimum fluoride removal with lime is achieved at a pH of 11, where fluoride has a solubility of 8 ppm.

TABLE 6. HYDROXIDE PRECIPITATION TEST RESULTS

RUN NO.	pH			
	PRECLAR. INF.	PILOT INF.	CLAR. EFF.	FILTER EFF.
13	8.1	8.2	9.6	9.5
14	-	8.0	10.1	9.9
15	-	7.7	10.3	10.3
16	7.6	7.8	10.3	10.2
17	-	7.9	10.1	10.2
18	-	7.7	9.9	9.9
19	8.1	8.0	10.0	9.9
20	-	7.8	9.9	9.8
21	-	7.7	9.8	9.7
22	-	7.6	9.8	9.8
23	7.8	7.6	9.8	9.7
24	-	7.8	9.9	9.9

TOTAL SUSPENDED SOLIDS (PPM)			
PRECLAR. INF.	PILOT INF.	CLAR. EFF.	FILTER EFF.
34	7	63	2
-	76	30	61
-	40	32	<1
380	3	65	<1
-	68	56	<1
-	52	22	3
74	<1	92	3
-	72	28	<1
-	18	36	41
-	45	84	2
83	48	57	<1
-	33	4	<1

RUN NO.	FLUORIDE (PPM)			
	PRECLAR. INF.	PILOT INF.	CLAR. EFF.	FILTER EFF.
13	20	19	22	24
14	-	20	18	17
15	-	22	13	12
16	270	13	12	11
17	-	17	16	16
18	-	13	26	17
19	270	58	17	13
20	-	30	14	18
21	-	17	15	15
22	-	15	12	12
23	210	27	13	12
24	-	25	43	24

TOTAL PHENOL (PPM)			
PRECLAR. INF.	PILOT INF.	CLAR. EFF.	FILTER EFF.
0.14	0.14	0.43	0.30
-	0.06	0.10	0.06
-	0.10	0.14	0.08
0.40	0.10	0.22	0.14
-	0.10	0.14	0.14
-	0.10	0.30	0.30
0.34	0.06	0.14	0.10
-	0.22	0.14	0.22
-	0.06	0.10	0.18
-	0.14	0.14	0.10
0.40	0.22	0.14	0.18
-	0.18	0.26	0.30

RUN NO.	CYANIDE (PPM)			
	PRECLAR. INF.	PILOT INF.	CLAR EFF.	FILTER EFF.
13	0.03	2.7	0.03	0.04
14	-	0.06	0.02	0.05
15	-	0.09	0.11	0.10
16	0.03	0.06	0.06	0.08
17	-	0.05	0.06	0.06
18	-	0.13	0.07	0.07
19	0.03	0.08	0.08	0.11
20	-	0.08	0.05	0.03
21	-	0.08	0.06	0.07
22	-	0.10	0.08	0.11
23	0.04	0.10	0.08	0.07
24	-	0.10	0.11	0.07

OIL & GREASE (PPM)			
PRECLAR INF.	PILOT INF.	CLAR. EFF.	FILTER EFF.
-	-	-	-
130	6	3	<1
270	7	3	<1
220	6	2	<1
160	4	1	4
240	4	1	3
220	5	5	3
210	4	4	2
76	4	4	2

TABLE 6. (CONTINUED) HYDROXIDE PRECIPITATION TEST RESULTS

RUN NO.	TOTAL CADMIUM (PPM)			
	PRECLAR INF.	PILOT INT.	CLAR. EFF.	FILTER EFF.
13	<0.010	<0.010	<0.010	<0.010
14	-	<0.010	<0.010	<0.010
15	-	<0.010	<0.010	<0.010
16	0.036	<0.010	<0.010	<0.010
17	-	<0.010	<0.010	<0.010
18	-	<0.010	<0.010	<0.010
19	<0.010	<0.010	<0.010	<0.010
20	-	<0.010	<0.010	<0.010
21	-	<0.010	<0.010	<0.010
22	-	<0.010	<0.010	<0.010
23	0.021	<0.010	<0.010	<0.010
24	-	<0.010	<0.010	<0.010

RUN NO.	TOTAL COPPER (PPM)			
	PRECLAR INF.	PILOT INT.	CLAR. EFF.	FILTER EFF.
13	0.072	0.022	<0.020	<0.020
14	-	0.033	<0.020	<0.020
15	-	0.025	<0.020	<0.020
16	0.130	0.037	<0.020	<0.020
17	-	0.028	<0.020	<0.020
18	-	<0.020	<0.020	<0.020
19	0.160	0.022	<0.020	<0.020
20	-	0.021	<0.020	<0.020
21	-	<0.020	<0.020	<0.020
22	-	<0.020	<0.020	<0.020
23	0.094	<0.020	<0.020	<0.020
24	-	0.049	<0.020	<0.020

RUN NO.	TOTAL NICKEL (PPM)			
	PRECLAR.INF.	PIL. INT.	CLAR.EFF.	FILT. EFF.
13	0.029	<0.010	<0.010	<0.010
14	-	<0.010	<0.010	<0.010
15	-	0.036	<0.010	<0.010
16	<0.010	<0.010	0.033	<0.010
17	-	0.020	<0.010	<0.010
18	-	<0.010	<0.010	<0.010
19	0.370	0.016	0.024	<0.010
20	-	<0.010	<0.010	<0.010
21	-	<0.010	<0.010	<0.010
22	-	<0.010	<0.010	<0.010
23	0.085	<0.010	<0.010	<0.010
24	-	<0.010	<0.010	<0.010

TOTAL SILVER (PPM)			
PRECLAR. INF.	PIL. INT.	CLAR. EFF.	FIL. EFF.
<0.010	<0.010	<0.010	<0.010
-	<0.010	<0.010	<0.010
-	<0.010	<0.010	<0.010
<0.010	<0.010	<0.010	<0.010
-	<0.010	<0.010	<0.010
-	<0.010	<0.010	<0.010
0.057	<0.010	<0.010	<0.010
-	<0.010	<0.010	<0.010
-	<0.010	<0.010	<0.010
-	<0.010	<0.010	<0.010
<0.010	<0.010	<0.010	<0.010
-	<0.010	<0.010	<0.010

TOTAL CHROMIUM (PPM)			
PRECLAR. INF.	PILOT INF.	CLAR EFF.	FILTER EFF
0.170	0.110	0.096	0.087
-	0.075	0.025	0.020
-	0.087	0.035	0.110
0.200	0.110	0.130	0.077
-	0.470	0.290	0.200
-	0.250	0.190	0.210
0.180	0.083	0.071	0.037
-	0.079	0.080	0.061
-	0.230	0.210	0.240
-	0.390	0.200	0.180
0.280	0.130	0.210	0.190
-	0.210	0.140	0.170

TOTAL LEAD (PPM)			
PRECLAR. INF.	PILOT INF.	CLAR EFF.	FILTER EFF
0.270	0.130	0.031	<0.020
-	0.150	0.180	<0.020
-	<0.020	<0.020	<0.020
1.10	0.200	<0.020	<0.020
-	0.170	<0.020	<0.020
-	0.093	<0.020	<0.020
1.10	0.061	<0.020	<0.020
-	0.041	<0.020	<0.020
-	0.087	<0.020	<0.020
-	0.046	<0.020	<0.020
0.960	0.036	<0.020	<0.020
-	0.120	<0.020	<0.020

TOTAL ZINC (PPM)			
PRECLAR.INF.	PIL.INF.	CLAR.EFF	FILTER EFF.
+2.8	3.8	0.08	<0.01
-	0.65	0.06	<0.01
-	0.43	0.03	0.01
13	0.61	0.02	0.01
-	0.49	0.04	<0.01
-	0.23	0.04	0.01
64	0.30	0.02	0.01
-	0.32	0.03	<0.01
-	0.21	0.04	<0.01
-	0.15	0.03	<0.01
+3.9	0.20	0.02	<0.01
-	0.13	0.03	<0.01

TABLE 7. HYDROXIDE PRECIPITATION DATA SUMMARY

Parameter	Preclarifier Influent(ppm) Mean	Range	Number of Samples*	Pilot Influent(ppm) Mean	Range	Number of Samples*	Clarifier Effluent(ppm) Mean	Range	Number of Samples*	Filter Effluent(ppm) Mean	Range	Number of Samples*
Suspended Solids	143	34-380	4	42	3-76	11	47	4-92	12	<2	<1-3	10
pH	7.9	7.6-8.1	4	7.8	7.6-8.2	12	9.9	9.6-10.3	12	9.9	9.5-10.3	12
Fluoride	193	20-270	4	23	13-58	12	15	12-22	10	16	11-24	12
Phenol	0.32	0.14-0.40	4	0.12	0.06-0.22	10	0.16	0.10-0.30	11	0.16	0.10-0.30	11
Cyanide	0.03	0.03-0.04	4	0.08	0.05-0.13	11	0.07	0.02-0.11	12	0.07	0.03-0.11	12
Oil & Grease	191	76-270	8	5	4-7	8	3	1-5	8	<2	<1-4	8
Total Cadmium	<0.019	<0.010-0.036	4	<0.010	<0.010	12	<0.010	<0.010	12	<0.010	<0.010	12
Total Chromium	0.209	0.170-0.280	4	0.185	0.075-0.470	12	0.140	0.025-0.290	12	0.132	0.020-0.240	12
Total Copper	0.114	0.072-0.160	4	<0.026	<0.020-0.049	12	<0.020	<0.020	12	<0.020	<0.020	12
Total Lead	0.86	0.27-1.1	4	0.096	<0.02-0.200	12	0.034	<0.020-0.180	12	<0.020	<0.020	12
Total Nickel	0.124	<0.010-0.370	4	0.014	<0.010-0.036	12	0.014	<0.010-0.033	12	<0.010	<0.010	12
Total Silver	<0.022	<0.010-0.057	4	<0.010	<0.010	12	<0.010	<0.010	12	<0.010	<0.010	12
Total Zinc	21	2.8-64	4	0.63	0.13-3.8	12	0.04	0.02-0.08	12	<0.01	<0.01-0.01	12

*Except for the Preclarifier, for which fewer samples were taken, the number of samples may vary due to unusually high or low data values which were dropped from the averages and ranges. Only 8 oil and grease samples were taken at each sampling point. All values are included in Table 6.

Phenols

No reduction in the phenols concentration was observed. This conforms to theory since adsorption of phenols onto the anthracite portion of the filter media (as discussed previously) would be more likely to take place in an acidic environment. In the case of activated carbon adsorption, phenols are actually desorbed in a strongly basic environment (4).

Cyanide

No reduction in the cyanide levels was observed.

Oil and Grease

Oil and grease was reduced to an average concentration of less than 2 ppm by the clarification and filtration steps. Most of the oil and grease was removed in the preclarification step. This is the expected result since oil and grease removal should be accomplished by BPT treatment.

Metals

Chromium --

An overall chromium reduction of 27 percent was achieved with hydroxide precipitation. The effluent concentration ranged from 0.020 to 0.240 ppm with an average of 0.132 ppm. Twenty-four percent of this removal took place in the clarification step. This may be attributed to particulate chromium becoming entrapped in the hydroxide floc and not to the formation of chromic hydroxide ($Cr(OH)_3$). As shown in Table 8, in most cases the soluble chromium concentration does not change significantly after lime addition and in some cases it increases slightly. There are two reasons for this. First, any hexavalent chromium (Cr(VI)) present in the wastewater must be reduced to trivalent chromium (Cr(III)) before it can be precipitated with lime. This process does not create the electrochemical conditions necessary to reduce Cr(VI) to Cr(III). Second, the solubility of $Cr(OH)_3$ at pH 10 is actually greater than the average influent concentration of soluble chromium, and therefore $Cr(OH)_3$ would not be precipitated. The optimum pH range for $Cr(OH)_3$ precipitation is approximately 7.5 to 9.0.

Copper and Lead --

Both copper and lead were removed to levels below the analytical detection limit for these metals with the addition of lime. Since they were present in the wastewater in particulate form only, their removal is attributed to their settling out in the clarifier with the hydroxide floc.

TABLE 8. COMPARISON OF TOTAL AND SOLUBLE METALS LEVELS FOR HYDROXIDE PRECIPITATION

RUN NO. 13

Parameter	Preclarifier Influent (ppm) Total	Preclarifier Influent (ppm) Soluble	Pilot Influent (ppm) Total	Pilot Influent (ppm) Soluble	Clarifier Effluent (ppm) Total	Clarifier Effluent (ppm) Soluble	Filter Effluent (ppm) Total	Filter Effluent (ppm) Soluble
Cadmium	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010
Chromium	0.170	0.043	0.011	0.061	0.096	0.077	0.087	0.079
Copper	0.072	<0.020	0.022	<0.020	<0.020	<0.020	<0.020	<0.020
Lead	0.270	<0.020	0.130	<0.020	0.031	<0.020	<0.020	<0.020
Nickel	0.029	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010
Silver	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010
Zinc	2.8	<0.01	3.8	0.18	0.08	<0.01	<0.01	<0.01

RUN NO. 16

Preclarifier Influent (ppm) Total	Preclarifier Influent (ppm) Soluble	Pilot Influent (ppm) Total	Pilot Influent (ppm) Soluble	Clarifier Effluent (ppm) Total	Clarifier Effluent (ppm) Soluble	Filter Effluent (ppm) Total	Filter Effluent (ppm) Soluble
0.036	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010
0.200	0.014	0.110	0.028	0.130	0.032	0.077	0.032
0.130	<0.020	0.037	<0.020	<0.020	<0.020	<0.020	<0.020
1.10	<0.020	0.200	<0.020	<0.020	<0.020	<0.020	<0.020
<0.010	<0.010	<0.010	<0.010	0.033	<0.010	<0.010	<0.010
<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010
13	<0.01	0.61	0.02	0.02	<0.01	0.01	<0.01

RUN NO. 17

Parameter	Preclarifier Influent (ppm) Total	Preclarifier Influent (ppm) Soluble	Pilot Influent (ppm) Total	Pilot Influent (ppm) Soluble	Clarifier Effluent (ppm) Total	Clarifier Effluent (ppm) Soluble	Filter Effluent (ppm) Total	Filter Effluent (ppm) Soluble
Cadmium	-	-	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010
Chromium	-	-	0.470	0.100	0.290	0.076	0.200	0.080
Copper	-	-	0.028	<0.020	<0.020	<0.020	<0.020	<0.020
Lead	-	-	0.170	<0.020	<0.020	<0.020	<0.020	<0.020
Nickel	-	-	0.020	<0.010	<0.010	<0.010	<0.010	<0.010
Silver	-	-	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010
Zinc	-	-	0.49	<0.01	<0.04	<0.01	<0.01	<0.010

RUN NO. 19

Preclarifier Influent (ppm) Total	Preclarifier Influent (ppm) Soluble	Pilot Influent (ppm) Total	Pilot Influent (ppm) Soluble	Clarifier Effluent (ppm) Total	Clarifier Effluent (ppm) Soluble	Filter Effluent (ppm) Total	Filter Effluent (ppm) Soluble
<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010
0.180	0.059	0.083	0.079	0.071	0.065	0.037	0.058
0.160	<0.020	0.022	<0.020	<0.020	<0.020	<0.020	<0.020
1.10	<0.020	0.061	<0.020	<0.020	<0.020	<0.020	<0.020
0.370	<0.010	<0.010	<0.010	0.024	<0.010	<0.010	<0.010
0.057	-	<0.010	-	0.024	<0.010	<0.010	-
64	<0.01	0.30	<0.01	0.02	<0.01	0.01	<0.01

RUN NO. 23

Parameter	Preclarifier Influent (ppm) Total	Preclarifier Influent (ppm) Soluble	Pilot Influent (ppm) Total	Pilot Influent (ppm) Soluble	Clarifier Effluent (ppm) Total	Clarifier Effluent (ppm) Soluble	Filter Effluent (ppm) Total	Filter Effluent (ppm) Soluble
Cadmium	0.021	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010
Chromium	0.280	0.110	0.130	0.060	0.210	0.070	0.190	0.090
Copper	0.094	<0.020	<0.020	<0.020	<0.020	<0.020	<0.020	<0.020
Lead	0.960	<0.020	0.036	<0.020	<0.020	<0.020	<0.020	<0.020
Nickel	0.085	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010
Silver	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010
Zinc	3.9	<0.01	0.20	<0.01	0.02	<0.01	<0.01	<0.01

Nickel --

There was very little nickel present in the wastewater during this phase of testing. Nickel was detected in runs 15 and 17 in low concentrations. With the addition of lime the concentration of nickel was reduced to below 0.010 ppm in both runs.

Zinc --

Zinc was significantly reduced with hydroxide precipitation. Better than 98 percent removal was achieved resulting in an average effluent concentration of less than 0.010 ppm. Ninety-four percent of this was removed in the clarification step. Since the zinc present in the wastewater was in the particulate form, its removal is attributed to its settling out in the clarifier with the hydroxide floc.

Sludge Production and Characteristics

Sludge production averaged 74 pounds of sludge at 14 percent solids per 1,000 gallons of wastewater treated over the hydroxide testing phase. On a dry weight basis, this amounted to 10.5 pounds per 1,000 gallons treated. This sludge would require dewatering before disposal.

Characteristics of the sludge produced during the hydroxide precipitation testing phase are presented in Table 9. The metals concentrations in the sludge are quite low, reflecting the low concentrations in the influent. The percent of total solids (TS) in the raw sludge is quite high. This is probably due to the fact that most of the metals in the wastewater were in the particulate form.

Data from the Buchner Funnel Tests conducted on the sludge samples is presented in Table 10. The sludge samples tested dewatered quite well. Their specific resistance values were in the range of 4.5×10^{10} to 2.4×10^{11} meters per kilogram (m/kg). This is well within the criteria for good dewatering by vacuum filter, which is equal to or less than 1×10^{12} m/kg.

Priority Pollutants

Priority pollutant organics were sampled for during one run for each treatment scheme. The three priority pollutants which have been selected as pollutants found in sintering wastewater are fluoranthene, pyrene and chrysene. These organic pollutants were detected during both runs in concentrations below 10 parts per billion (ppb). Although the compounds were not detected at every sampling location, this probably results from concentrations close to the analytical detection limit. Other priority pollutants were detected at

TABLE 9. HYDROXIDE SLUDGE COMPOSITION

Run No.	Total Cadmium (ppm)(2)	Total Chromium (ppm)	Total Copper (ppm)	Total Lead (ppm)	Total Nickel (ppm)	Total Silver (ppm)	Total Zinc (ppm)	TS(1) (%)
17	0.55	2.2	8.3	17	3.1	0.55	278	5.4
20	0.20	0.65	2.3	5.0	1.1	0.10	220	20
22	0.13	0.80	2.9	7.3	1.3	0.20	80	15
24	0.12	0.75	2.8	6.2	1.0	0.12	75	16

1. Total Solids in percent by weight.
2. Concentration in mg metal per kg dry sludge solids (ppm).

TABLE 10. BUCHNER FUNNEL TEST RESULTS FOR HYDROXIDE SLUDGE

Run No.	Raw TS (%)	Dewatered(1) TS (%)	Specific Resistance (m/kg)
17	5.4	79	2.39×10^{11}
20	20	19	4.50×10^{10}
22	15	8.3(2)	7.76×10^{10}
24	16	45	7.18×10^{10}

1. Dewatered total solids values for The Buchner Funnel Test are usually higher than those achievable on full scale equipment.
2. Questionable value due to insufficient sample size.

low concentrations and are listed in Table 11. Two of the compounds that were detected, methylene chloride and bis(2-ethylhexyl)-phthalate, are believed to have been introduced to the samples extraneously through glassware cleaning procedures, which call for methylene chloride, and the use of plastic tubing for sample collection, which has been known to introduce phthalates into water.

EFFLUENT LIMITATIONS

The promulgated effluent limitations for the sintering subcategory of the iron and steel industry are presented in Table 12 (1). These limitations included both BAT and BPT. These are new BPT limitations, different from those originally promulgated in 1974. The limitations are presented solely for the purpose of comparison with effluent levels achieved during pilot plant operation. For the purpose of comparison, the EPA model plant flow of 75 gallons per ton of steel produced was employed. Because the limitations are presented as kg/kkg of product the volume of discharge dictates the permissible effluent concentration.

Of the EPA-selected pollutant parameters for sintering, limitations have been promulgated for total suspended solids, oil and grease, ammonia, cyanide, phenols, TRC, lead and zinc. When comparing the pilot data to the effluent limitations it is important to consider the influent concentrations. With the exception of zinc and suspended solids the concentrations of all parameters for which BAT and BPT limitations were promulgated met these limitations after preclarification. Zinc exceeded the BAT daily maximum limitation three times and exceeded the BAT average limitation. Suspended solids exceeded the BPT average limitation.

Both the individual effluent zinc concentrations and the average concentration fell below the BAT maximum and average limitation after treatment by either direct filtration or hydroxide precipitation with filtration.

The average suspended solids levels fell well below the average BPT limitation after treatment by either process.

In summary, both treatment alternatives produced an effluent that met all of the limitations. Limitations for all parameters except zinc and suspended solids were met after the initial preclarification step which was intended to simulate BPT treatment.

TABLE 11. PRIORITY POLLUTANTS

Compound	Run No. 7 - Direct Filtration			Run No. 19 - Hydroxide ppt.		
	Pilot Inf. (ppb)	Clarifier Eff. (ppb)	Filter Eff. (ppb)	Pilot Inf. (ppb)	Clarifier Eff. (ppb)	Filter Eff. (ppb)
Benzene	<10.		<10.	<10.	<10.	<10.
Chlorobenzene	<10.		ND	ND	ND	ND
Chloroform	ND		ND	ND	ND	ND
Methylene Chloride	430.		57.	ND	ND	ND
Toluene	<10.		<10.	ND	ND	ND
Anthracene	<10.		<10.	<10.	<10.	<10.
Fluoranthene	<10.		<10.	ND	<10.	ND
Pyrene	<10.		<10.	ND	<10.	ND
Chrysene	<10.		ND	<10.	ND	<10.
Bis(2-ethylhexyl)-phthalate	<10.		<10.	<10.	<10.	<10.
Phenol	ND		ND	ND	14.	ND
2-nitrophenol	44.		33.	ND	ND	ND
2.4-dimethylphenol	ND		ND	<10.	<10.	<10.
2-nitro-4-methylphenol	*		*	ND	ND	ND

* Non-priority pollutant compound tentatively identified but not quantitated.
ND Not detected.

TABLE 12. PROMULGATED BPT AND BAT EFFLUENT LIMITATIONS

	Average		Maximum	
	Concentration Basis (ppm)(1)	Effluent limitation (kg/kkg product)	Concentration Basis (ppm)(1)	Effluent limitation (kg/kkg product)
BPT		-		
Total Suspended Solids	90	0.0250	275	0.0751
Oil and Grease	20	0.00501	50	0.0150
pH	Within the range of 6.0 to 9.0			
BAT				
Ammonia (N)(2)	20	0.00501	50	0.0150
Total Cyanide(2)	2.0	0.000501	4.0	0.0010
Phenols(2)	0.20	0.0000501	0.35	0.0001
TRC(2)	-	-	0.90	0.00025
Lead	0.50	0.000125	1.5	0.000375
Zinc	0.55	0.000150	1.5	0.000450

1. Limitations are in kg/kkg of product. Concentrations were calculated using the EPA model plant flow of 75 gallons per ton of product.

2. The limitations for ammonia - N, cyanide, phenols (4AAP) and TRC apply only when sintering wastewaters are treated with iron making wastewater.

SECTION 7

ESTIMATED CONSTRUCTION AND OPERATING COSTS

Construction and operating costs were estimated for the direct filtration and hydroxide precipitation treatment process trains. Construction costs were developed for treatment facilities designed by incorporating input from the pilot plant operation experience with normal process design considerations. Equipment was sized for the EPA model plant production and blowdown rates for the sintering subcategory. Chemical usage and labor requirements were based largely on pilot plant data and operating experience. No scale-up factors were employed because they were not considered to be necessary.

The costs have been developed primarily as estimates for the treatment alternatives under consideration to serve as a basis from which economic comparisons of the alternatives may be made. Generalized BAT model treatment plants were employed in developing costs. These model plants were designed as "add-on" facilities to existing BPT systems for upgrading to BAT treatment. Therefore, it was assumed that the influent wastewater to the BAT facilities was already of BPT effluent quality.

EQUIPMENT SIZING

The design flow rate employed for equipment sizing was based on the EPA-designated model sinter plant. The model plant produces 4,000 tons of product per day and discharges 75 gallons of blowdown per ton. This amounts to 300,000 gpd (208 gpm) of blowdown requiring BAT treatment. Thus, the design flow of 208 gpm was employed for the purpose of equipment sizing and process alternative comparisons. The treatment facilities were sized for continuous operation.

BAT Treatment Facilities

Dual Media Filtration --

The design data for dual media filtration are presented in Table 13.

TABLE 13. FILTER DESIGN DATA

Design flow, gpm	208
Filtration rate, gpm/ft^2	5
Total filter area, ft^2	42
Number of filters	3
Area per filter, ft^2	20
Filter diameter, ft	5
Media depth	
Anthracite, in.	24
Sand, in.	12
Gravel, in.	12
Backwash cycle, min.	20

Filtration facilities include the following:

1. Filter vessels and components
2. Media
3. Pumps
4. Instrumentation and controls
5. Backwash storage tank
6. Piping and valves
7. Electrical work
8. Building.

Three filters were included to allow continuous operation during backwashing. Redundancies were also provided in both the filter influent and backwash pumps.

The spent backwash water would be recycled back to the BPT clarifier for treatment. It would first be diverted to an equalization basin then gradually bled into the BPT clarifier at a rate which would not upset that operation. Although these solids did not settle out in the BPT clarifier initially, the chances of their settling out after being returned to the clarifier in the filter backwash is greater due to agglomeration in the filter and entrainment in oil and grease which acts as a binder. Because of this system of recycle, no additional facilities would be required for the treatment of spent backwash water except for the equalization basin.

Hydroxide Precipitation --

The design data for the hydroxide precipitation facility are presented in Table 14. This facility includes the following:

1. Rapid mix tanks and mixers
2. Flocculator-clarifier or inclined plate separator with flocculator
3. Pumps for wastewater, sludge, backwash
4. Chemical feed system with pH control
5. Chemical batching tanks
6. Dual media filters and components
7. Filter media
8. Backwash storage tanks
9. Instrumentation and controls
10. Pipes and valves
11. Electrical work
12. Building.

TABLE 14. HYDROXIDE PRECIPITATION/CLARIFICATION DESIGN DATA

	Clarifier	Inclined plate separator
Design flow, gpm	208	208
Rapid mix detention time, min.	10	10
Flocculator detention time, min.	20	20
Gravity settler:		
Detention time, hr.	3.8	-
Overflow rate, gpm/ft^2	0.29	0.24
Settling area, ft^2	706*	860*
Angle of incline, degrees	-	55

*These numbers are based on the manufacturers standard sizes.

Three filters were included to allow continuous operation during backwashing. Redundancies were also provided in the process flow, chemical feed, backwash and sludge pumps.

Two gravity settling equipment alternatives were considered: clarifiers and inclined plate separators. Clarifiers are conventional equipment and were employed in the pilot plant testing as the available equipment in the MWWTS. The inclined plate separator has been included as an alternative means of gravity settling. The inherent advantage of an inclined plate separator over a conventional clarifier is that plate separator requires significantly less space. Based on manufacturers' literature for settling of hydroxide sludges(3) inclined plate separators performed comparably to conventional clarifiers at comparable overflow rates. Therefore, the same overflow rate was used to size both types of units. As a result of standard sizes for equipment, a fairly conservative overflow rate resulted for both types of equipment.

The quantity of sludge produced by the hydroxide precipitation process is relatively small compared with the quantity of sludge generated in BPT treatment. It is likely that BAT sludge would be blended with the BPT sludge and dewatered on existing BPT equipment without significantly impacting those operations. It was, therefore, assumed that BAT sludge would require no additional dewatering and disposal facilities. However, there is a potential that separate sludge treatment and disposal facilities would be required if the BAT sludge is classified as hazardous under the Resource Conservation and Recovery Act of 1976 (RCRA) and the BPT sludge is not classified as hazardous. EP toxicity tests were not performed on the sludges. At the present time sinter plant sludge is not listed as a hazardous waste.

COST ESTIMATES

Construction Costs

Capital costs for the facilities for each treatment process alternative were largely based on vendor quotations and normal estimating considerations. All costs were current for the third quarter of 1981. In addition to the installed capital costs for the equipment as described in the previous sections, construction costs include estimated costs for site work, excavation, gravel and concrete.

In developing these cost estimates, the effort was made to provide a realistic and representative estimate for implementation of the BAT treatment alternatives. However, there are site-specific costs which will influence actual costs for any facility. In addition to these site-specific costs, there are

a few other costs which have not been included. The construction cost estimates do not include the following:

1. Land aquisition/space allocation
2. Ancillary facilities
3. Retrofitting/process equipment adaptation
4. Equipment replacement
5. Back-up facilities, except those normally engineered into wastewater treatment design
6. Utility and yard services
7. Start-up costs
8. Indirect costs (Interest during construction, insurance).

The itemized construction costs are presented in Appendix C. Total construction costs have been summarized in Table 15 for the BAT alternatives. Engineering and construction management costs were estimated at 20 percent of the construction cost. Contingency was estimated at 15 percent of construction and engineering costs. The total capital costs were amortized over a 10-year period at an 18 percent rate. Amortized capital costs are also presented in Table 15.

Note that there is only one set of costs for the hydroxide precipitation process alternative. Although both the clarifier and inclined plate separator options were considered, their installed costs (Appendix C) were not found to be significantly different. Only the costs for the clarifier option have been shown in Table 15.

Operating Costs

Annual operating costs were estimated for the BAT process alternatives. Operating costs include:

1. Labor
2. Chemicals
3. Power
4. Maintenance (materials and labor).

They do not include supervisory costs or costs for analytical services.

TABLE 15. SUMMARY OF ANNUAL CAPITAL AND OPERATING COSTS*

Item	Hydroxide Precipitation	Direct Filtration
Construction Costs	571,500	362,900
Engineering and Constr. Management, 20%	114,300	72,600
Contingency, 15% of Constr. and Engrg.	85,700	54,400
Total Capital Cost	771,500	489,900
Amortized Capital Cost (10 yr. at 18%)	171,700	109,000
Annual Operating Costs		
Labor	70,000	70,000
Chemicals	19,000	0
Power	6,100	2,000
Maintenance (Materials and Labor)	7,700	4,900
Total	102,800	76,900
Total Annual Cost	274,500	185,900
$/1,000 gal treated	$2.51	$1.70

*Based on third quarter of 1981.

Operating labor was estimated to be two 6-hour shifts per day with one man per shift for direct filtration and hydroxide precipitation. Chemical batching and monitoring would be accomplished during these shifts. Because these processes operate automatically, they would not need to be manned 24 hours per day. In the off-shift, they would be checked periodically by a BPT treatment operator. Labor was estimated at $35,000 per man-year, based on a 7-day week.

Annual operating costs are summarized in Table 15. Chemical usage for the hydroxide precipitation process was calculated from pilot plant operation. Chemical costs were based on prices current in the third quarter of 1981. Chemical requirements and prices are presented in Table 16. Power requirements were determined for the treatment facilities. Power costs were based on a rate of $0.031/kwh. Maintenance costs were estimated at one percent of the total capital cost.

TABLE 16. CHEMICAL REQUIREMENTS AND COSTS FOR HYDROXIDE PRECIPITATION*

Chemical	Chemical Prices ($/ton)	Chemical Requirements and Costs (lb/day)	($/day)
Hydrated Lime	42.50	1,010	21
Sulfuric Acid (66 deg Baume)	69.20	900	31

*Based on third quarter of 1981.

Total Annual Cost

The amortized capital cost and the annual operating costs were summed to establish the total annual costs for the BAT treatment facilities. These costs, summarized in Table 15, formed the basis from which the economic evaluations were made.

SECTION 8

COMPARISON OF TREATMENT ALTERNATIVES

The relative effectiveness of the alternative treatment systems has been evaluated based on process performance, operational control and relative cost of treatment. Direct filtration is clearly less expensive than hydroxide precipitation followed by filtration and, therefore, no further economic comparison was made. The direct filtration and hydroxide precipitation plus filtration alternatives were compared with respect to effectiveness in removal of the selected pollutant parameters.

PROCESS PERFORMANCE

A high quality effluent was produced by both treatment alternatives. In most of the test runs good removal of suspended solids and heavy metals was achieved. Comparisons were made and the processes evaluated based on their effectiveness in removing the selected pollutants. The effluent concentrations for the direct filtration and hydroxide precipitation alternatives are presented in Table 17.

Suspended Solids

The two alternative treatment trains were equally effective in removing suspended solids to a level which complies with the regulations. The mean effluent values from both alternatives were below 5 ppm and, with the exception of one value, the maximum concentrations were less than 10 ppm. During the hydroxide precipitation runs, a substantial amount of solids carryover from the clarifier occurred but this was subsequently removed by filtration.

Fluoride

A mean effluent fluoride level of 16 ppm was achieved by both direct filtration and hydroxide precipitation followed by filtration. During the hydroxide precipitation test phase, the mean influent concentration was greater, therefore a larger reduction in fluoride was achieved with hydroxide precipitation. This would be expected since the lime added to the wastewater provides a source of calcium ions needed to

TABLE 17. COMPARISON OF FINAL EFFLUENT CONCENTRATIONS

Parameter	Direct Filtration		Hydroxide Precipitation	
	Mean (ppb)	Range (ppb)	Mean (ppb)	Range (ppb)
Suspended Solids	3	1-7	<2	<1-3
pH	7.8	6.9-9.0	9.9	9.5-10.3
Fluoride	16	10-34	16	11-24
Phenol	0.07	0.01-0.22	0.16	0.06-0.30
Cyanide	0.130	0.034-0.260	0.070	0.030-0.110
Oil & Grease	<6	<5-9	<2	<1-4
Total Cadmium	<0.010	<0.010-0.013	<0.010	<0.010
Total Chromium	0.170	<0.010-0.430	0.132	0.020-0.240
Total Copper	<0.020	<0.020-0.026	<0.020	<0.020
Total Lead	<0.020	<0.020	<0.020	<0.020
Total Nickel	0.013	<0.010-0.023	<0.010	<0.010
Total Silver	<0.010	<0.010	<0.010	<0.010
Total Zinc	0.18	0.06-0.47	<0.010	<0.010-0.010

precipitate calcium fluoride (CaF_2). The removal of fluoride during the direct filtration phase was probably due to entrainment of particulate fluoride, such as CaF_2 or hydroxyapatites, in the filter. This could be due to the presence of calcium hardness in the sinter plant blowdown.

Cyanide

Neither process had any significant effect on cyanide. This is the expected result since neither process provides the necessary reaction for cyanide destruction to more benign substances. The influent concentration throughout the test phases met the BAT effluent limitation.

Phenols

Some removal of phenols was observed during direct filtration whereas no removal was achieved with hydroxide precipitation. It was found that the average clarifier and filter effluent concentrations during the hydroxide precipitation runs were higher than the influent concentration. The possibility of phenols being adsorbed onto the anthracite portion of the filter media in the direct filtration runs was considered. No phenol reduction occurred during filtration in the hydroxide precipitation phase. This conforms to theory since optimum adsorption of phenols takes place in an acidic environment and, in the case of activated carbon, is desorbed in a strongly basic environment (4). It was also possible that phenol was adsorbed onto suspended solid matter or oil and grease in the wastewater. This would account for the decrease in phenols after preclarification and for the increase in phenols in the clarifier and filter effluents during hydroxide precipitation.

Oil and Grease

Some oil and grease reduction was achieved by both processes. In all of the runs, the effluent oil and grease concentrations were below the BPT limit. Significant reductions occurred only across the preclarifier.

Metals

Chromium --

Both direct filtration and hydroxide precipitation were effective in reducing particulate chromium to some degree. No soluble chromium was removed due to lack of reducing agents to reduce Cr(VI) to Cr(III). In addition, the operating pH was too high during hydroxide precipitation for good $Cr(OH)_3$ precipitation.

Copper and Lead --

Low concentrations of copper and lead were present in the wastewater in particulate form only. Direct filtration and hydroxide precipitation were equally effective in their removal to average concentrations below the analytical detection limit of 0.02 ppm.

Nickel --

Very little nickel was present in the wastewater throughout the duration of the study. When nickel was present in detectable quantities, good removal was accomplished with both treatment alternatives.

Zinc --

Both alternatives achieved good zinc removal. It was noticed that a change in the influent zinc concentrations occurred from one test phase to the other. A somewhat greater portion of the total influent zinc was in the soluble form during the direct filtration phase, while most of the influent zinc during the hydroxide precipitation phase was in the particulate form. Variations in the quantities of soluble and particulate zinc would affect the ability of direct filtration to consistently remove it from the wastewater. Hydroxide precipitation should not be affected by this.

INTEGRATED EVALUATION

An integrated evaluation of the direct filtration and hydroxide precipitation, followed by filtration, alternatives was made based on performance, operational control and relative cost of treatment. In making this evaluation, the major objective was taken to be the ability of the processes to remove the selected pollutant parameters for the sinter plant blowdown consistently and reliably. This was not an evaluation of the effluent limitations and should not be construed as such. No effluent guidelines were employed; the evaluation was qualitative and semi-quantitative.

Direct filtration was effective in removing all of the selected pollutant parameters found to be present in the sinter plant blowdown in significant quantities. The degree of chromium and zinc removal varied with varying levels of soluble chromium and zinc in the influent. Cyanide, which was present in very low levels, was not affected. Filter operation is simple and easily controlled, requiring minimal operator attention. No sludge is produced. The backwash solids load that is intermittently generated could be recycled to the head of most existing BPT treatment systems without any additional treatment.

Hydroxide precipitation was effective in removing all of the selected pollutant parameters found to be present in significant quantities except for phenols. The degree of chromium removal varied with the level of soluble influent chromium. Cyanide, which was present in very low levels, was not affected. Operation is straight-forward and could be automatically controlled with a high level of reliability. Operations manpower would be mainly for lime slurry batching, system monitoring and routine maintenance. At most plants, the waste sludge which is produced can be treated and disposed of along with sludge from existing clarification systems by employing existing facilities.

Both treatment alternatives performed well. However, neither performed significantly better than the other. Hydroxide precipitation achieved slightly lower residuals for most parameters than direct filtration. Direct filtration produced a high quality effluent at a significantly lower cost (Table 15) and less operational considerations and, therefore, best achieved the goals of BAT.

Because heavy metals in the sinter plant blowdown were predominantly in the particulate form, direct filtration was effective in removing them. If significant quantities of soluble metals had been present, the effectiveness would have been considerably less. Therefore, this evaluation is based on the sinter plant blowdown that was treated during the study being representative.

REFERENCES

1. Environmental Protection Agency, Effluent Guidelines and Standards for Iron and Steel Manufacturing, 40 CFR 420; 39 FR 24114, June 28, 1974; Amended as shown in Code of Federal Regulations, Volume 40, Revised as of July 1, 1981; Revised by 47 FR 23285, May 27, 1982.

2. Robinson, A. K., and J. C. Sum. "Sulfide Precipitation of Heavy Metals," EPA-600/2-80-139, U.S. Environmental Protection Agency, Cincinnati, Ohio, June 1980.

3. Janerus, I. V., and D. K. Lucas. "Settling and Thickening Metal Hydroxides with the Lamella Gravity Settlers," presented at the Pennsylvania Water Pollution Control Association, Hersey Technical Conference, Hersey, Pennsylvania, June 15, 1977.

4. Berkowitz, J. B., J. T. Funkhouser and J. I. Stevens, Arthur D. Little, Inc. Unit Operations for Treatment of Hazardous Industrial Wastes. Noyes Data Corporation, Park Ridge, New Jersey, 1978.

5. "Development Document for Effluent Limitations Guidelines and Standards for the Iron and Steel Manufacturing Point Source Category" Volume II EPA 440/1-80/024b, U.S. Environmental Protection Agency, Washington, D.C., December 1980.

APPENDIX A

PLANT PRODUCTION DATA

TABLE A-1. ARMCO SINTER PLANT PRODUCTION DATA

Date	Tons of Product	Date	Tons of Product
2/2/81	1653	2/15	824
2/3	1464.5	2/16	1188.5
2/4	1153	2/17	1461
2/5	1377	2/18	1371.5
2/6	1804	2/19	1394.5
2/7	1447.5	2/20	1058
2/8	1081	2/21	1608.5
2/9	1555	2/22	1638
2/10	1536	2/23	1646.5
2/11	1137.5	2/24	1301.5
2/12	501.5	2/25	1268.5
2/13	1597	2/26	1377
2/14	1402.5	2/27	1113
		2/28	180

APPENDIX B

BENCH SCALE DATA

TABLE B-1. HYDROXIDE PRECIPITATION
BENCH SCALE TEST DATA

Parameter	Raw WW pH 8.8	Test Sample 1 pH 9.0	2 pH 9.5	3 pH 10.0	4 pH 10.5	5 pH 11.0
SS	110	70	40	90	110	100
Tot. Cd	0.02	0.01	0.03	0.01	0.02	0.01
Tot. Cr	0.25	0.17	0.17	0.18	0.16	0.19
Tot. Cu	0.05	0.03	0.03	0.03	0.03	0.02
Tot. Pb	0.80	0.19	0.19	0.21	0.18	0.19
Tot. Ni	0.05	<0.04	<0.04	<0.04	<0.04	<0.04
Tot. Ag	0.07	0.03	0.04	0.04	<0.01	0.01
Tot. Zn	0.36	0.07	0.07	0.06	0.05	0.04
Tot. Fe	20	2.4	2.4	2.0	1.2	1.1

TABLE B-2. ALKALINE CHLORINATION
BENCH SCALE TEST DATA

	Test Sample					
	Raw WW	A pH 10.5	B pH 10.5	C pH 10.5	D pH 10.5	E pH 10.5
NaOCl Dosage (mg/l)	-	83	167	250	375	500
Chlorine Residual Free (mg/l)	-	20	44	114	132	228
Total (mg/l)	-	30	56	120	248	444
CN-(mg/l)	0.08	0.013	<0.010	<0.010	<0.010	0.016
NH_3-N (mg/l)	2.7	3.5	1.0	0.90	<0.02	<0.02

APPENDIX C

COST ESTIMATES

TABLE C-1. CONSTRUCTION COST ESTIMATE FOR THE DIRECT FILTRATION ALTERNATIVE

Dual Media Filter	150,500
Building and Foundation	53,350
Total Installed Major Equipment Cost	203,850
Instrumentation and Controls, 18%	36,700
Piping and Valving, 30%	61,200
Electrical, 10%	20,400
Site Work, 20%	40,800
Total	362,950

TABLE C-2. CONSTRUCTION COST ESTIMATE FOR THE HYDROXIDE PRECIPITATION ALTERNATIVE

	Clarifier	Inclined Plate Separator
Lime Make-up and Feed System	21,700	21,700
Flocculator/Gravity Settler	81,400	75,400
Dual Media Filter	150,500	150,500
Acid Neutralization System	11,000	11,000
Building and Foundation	56,500	56,500
Total Installed Major Equipment Cost	321,100	315,100
Instrumentation and Controls, 18%	57,800	56,700
Piping and Valving, 30%	96,300	94,500
Electrical, 10%	32,100	31,500
Site Work, 20%	64,200	63,000
Total Construction Cost	571,500	560,800